

GCSE (9–1)
Specification

TWENTY FIRST CENTURY SCIENCE COMBINED SCIENCE B

J260
For first assessment in 2018

In partnership with

**UNIVERSITY OF YORK
SCIENCE EDUCATION GROUP**

Version 3.2 (February 2019)



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Specifications are updated over time. Whilst every effort is made to check all documents, there may be contradictions between published resources and the specification, therefore please use the information on the latest specification at all times. Where changes are made to specifications these will be indicated within the document, there will be a new version number indicated, and a summary of the changes. If you do notice a discrepancy between the specification and a resource please contact us at: resources.feedback@ocr.org.uk

We will inform centres about changes to specifications. We will also publish changes on our website. The latest version of our specifications will always be those on our website (ocr.org.uk) and these may differ from printed versions.

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Support and Guidance

Introducing a new specification brings challenges for implementation and teaching, but it also opens up new opportunities. Our aim is to help you at every stage. We are working hard with teachers and other experts to bring you a package of practical support, resources and training.

Subject Advisors

OCR Subject Advisors provide information and support to centres including specification and non-exam assessment advice, updates on resource developments and a range of training opportunities.

Our Subject Advisors work with subject communities through a range of networks to ensure the sharing of ideas and expertise supporting teachers and students alike. They work with developers to help produce our specifications and the resources needed to support these qualifications during their development.

You can contact our **Science** Subject Advisors for specialist advice, guidance and support:

01223 553998

ScienceGCSE@ocr.org.uk
[@OCR_Science](https://www.ocr.org.uk/@OCR_Science)

Teaching and learning resources

Our resources are designed to provide you with a range of teaching activities and suggestions that enable you to select the best activity, approach or context to support your teaching style and your particular students. The resources are a body of knowledge that

will grow throughout the lifetime of the specification, they include:

- Delivery Guides
- Transition Guides
- Topic Exploration Packs
- Lesson Elements.

We also work with a number of leading publishers who publish textbooks and resources for our specifications. For more information on our publishing partners and their resources visit: ocr.org.uk/qualifications/gcse-and-a-level-reform/publishing-partners

Professional development

Our improved Professional Development Programme fulfils a range of needs through course selection, preparation for teaching, delivery and assessment. Whether you want to come to face-to-face events, look at our new digital training or search for training materials, you can find what you're looking for all in one place at the CPD Hub: cpdhub.ocr.org.uk

An introduction to new specifications

We run training events throughout the academic year that are designed to help prepare you for first teaching and support every stage of your delivery of the new qualifications.

To receive the latest information about the training we offer on GCSE and A Level, please register for email updates at: ocr.org.uk/updates

Assessment Preparation and Analysis Service

Along with subject-specific resources and tools, you'll also have access to a selection of generic resources that

focus on skills development, professional guidance for teachers and results data analysis.





1 Why choose an OCR GCSE (9–1) in Combined Science B (Twenty First Century Science)?

1a. Why choose an OCR qualification?

Choose OCR and you've got the reassurance that you're working with one of the UK's leading exam boards. Our new OCR GCSE (9–1) in Combined Science B (Twenty First Century Science) course has been developed in consultation with teachers, employers and higher education to provide learners with a qualification that's relevant to them and meets their needs.

We're part of the Cambridge Assessment Group, Europe's largest assessment agency and a department of the University of Cambridge. Cambridge Assessment plays a leading role in developing and delivering assessments throughout the world, operating in over 150 countries.

We work with a range of education providers, including schools, colleges, workplaces and other institutions in both the public and private sectors. Over 13,000 centres choose our A Levels, GCSEs and vocational qualifications including Cambridge Nationals and Cambridge Technicals.

Our Specifications

We believe in developing specifications that help you bring the subject to life and inspire your learners to achieve more.

We've created teacher-friendly specifications based on extensive research and engagement with the teaching community. They're designed to be straightforward and accessible so that you can tailor the delivery of the course to suit your needs. We aim to encourage learners to become responsible for their own learning, confident in discussing ideas, innovative and engaged.

We provide a range of support services designed to help you at every stage, from preparation through to the delivery of our specifications. This includes:

- A wide range of high-quality creative resources including:
 - Delivery Guides
 - Transition Guides
 - Topic Exploration Packs
 - Lesson Elements
 - ...and much more.
- Access to Subject Advisors to support you through the transition and throughout the lifetime of the specification.
- CPD/Training for teachers including face-to-face events to introduce the qualifications and prepare you for first teaching.
- Active Results – our free results analysis service to help you review the performance of individual learners or whole schools.
- [ExamBuilder](#) – our free online past papers service that enables you to build your own test papers from past OCR exam questions.

All GCSE (9–1) qualifications offered by OCR are accredited by Ofqual, the Regulator for qualifications offered in England. The accreditation number for OCR's GCSE (9–1) in Combined Science B (Twenty First Century Science) is QN 601/8690/2.

1b. Why choose an OCR GCSE (9–1) in Combined Science B (Twenty First Century Science)?

We appreciate that one size doesn't fit all so we offer two suites of qualifications in each science:

Combined Science A (Gateway Science) – Provides a flexible approach to teaching. The specification is divided into topics, each covering different key concepts of biology, chemistry and physics. Teaching of practical skills is integrated with the theoretical topics and they are assessed through the written papers.

Combined Science B (Twenty First Century Science) – Learners study biology, chemistry and physics using a narrative-based approach. Ideas are introduced within relevant and interesting settings which help learners to anchor their conceptual knowledge of the range of scientific topics required at GCSE level. Practical skills are embedded within the specification and learners are expected to carry out practical work in preparation for a written examination that will specifically test these skills.

Combined Science B (Twenty First Century Science) has been developed with the University of York

Science Education Group (UYSEG) in conjunction with subject and teaching experts. Together we have aimed to produce a specification with up to date relevant content accompanied by a narrative to give context and an idea of the breath of teaching required. Our new GCSE (9–1) in Combined Science B (Twenty First Century Science) qualification builds on our existing popular course. We have based the development of our GCSE (9–1) sciences on an understanding of what works well in centres large and small. We have undertaken a significant amount of consultation through our science forums (which include representatives from learned societies, HE, teaching and industry) and through focus groups with teachers.

The content is clear and logically laid out for both existing centres and those new to OCR, with assessment models that are straightforward to administer. We have worked closely with teachers to provide high quality support materials to guide you through the new qualifications.

Aims and learning outcomes

GCSE study in Combined Science provides the foundation for understanding the material world. Scientific understanding is changing our lives and is vital to the world's future prosperity, and all learners should be taught essential aspects of the knowledge, methods, process 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.

The Twenty First Century Science suite will enable learners 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

1c. What are the key features of this specification?

Building on research, and on the principles of *Beyond 2000*, the Twenty First Century Science suite was originally developed by the University of York Science Education Group (UYSEG), the Nuffield Foundation and OCR.

The 2016 suite continues to recognise the diversity of interests and future intentions of the learner population who take a science qualification at GCSE level. The specifications will prepare learners for progression to further study of science, whilst at the same time offering an engaging and satisfying course for those who choose not to study academic science further.

The Twenty First Century Science suite will:

- take opportunities to link science to issues relevant to all learners as citizens, and to the

cultural aspects of science that are of value and interest to all

- develop learners' abilities to evaluate knowledge claims critically, by looking at the nature, quality and extent of the evidence, and at the arguments that link evidence to conclusions
- develop learners' understanding of the concepts and models that scientists use to explain natural phenomena
- develop learners' ability to plan and carry out practical investigations and their understanding of the role of experimental work in developing scientific explanations.

1d. How do I find out more information?

Whether new to our specifications, or continuing on from our legacy offerings, you can find more information on our webpages at www.ocr.org.uk

Visit our subject pages to find out more about the assessment package and resources available to support your teaching. The science team also release a termly newsletter *Science Spotlight* (despatched to centres and available from our subject pages).

If you are not already a registered OCR centre then you can find out more information on the benefits of becoming one at: www.ocr.org.uk

If you are not yet an approved centre and would like to become one go to: www.ocr.org.uk/approvals

Want to find out more?

You can contact the Science Subject Advisors:

Email: ScienceGCSE@ocr.org.uk,

Telephone: 01223 553998

Join our Science community: <http://social.ocr.org.uk/>

Check what CPD events are available: www.cpdhub.ocr.org.uk

Follow us on Twitter: https://twitter.com/ocr_science

2 The specification overview

2a. OCR's GCSE (9–1) in Combined Science B (Twenty First Century Science) (J260)

Learners are entered for either Foundation Tier (components 01–04) **or** Higher Tier (components 05–08). This qualification is worth two GCSEs.

Content Overview	Assessment Overview	
Foundation Tier, grades 1–1 to 5–5		
<p>Content is split into twenty teaching chapters:</p> <ul style="list-style-type: none">• Chapter B1: You and your genes• Chapter B2: Keeping healthy• Chapter B3: Living together – food and ecosystems• Chapter B4: Using food and controlling growth• Chapter B5: The human body – staying alive• Chapter B6: Life on Earth – past, present and future• Chapter C1: Air and water• Chapter C2: Chemical patterns• Chapter C3: Chemicals of the natural environment• Chapter C4: Material choices• Chapter C5: Chemical analysis• Chapter C6: Making useful chemicals• Chapter P1: Radiation and waves• Chapter P2: Sustainable energy• Chapter P3: Electric circuits• Chapter P4: Explaining motion• Chapter P5: Radioactive materials• Chapter P6: Matter – models and explanations• Chapter BCP7: Ideas about Science• Chapter BCP8: Practical Skills <p>Paper 1 assesses content B1 – B6 and BCP7 and 8</p> <p>Paper 2 assesses content C1 – C6 and BCP7 and 8</p> <p>Paper 3 assesses content P1 – P6 and BCP7 and 8</p> <p>Paper 4 assesses all content</p>	<p>Biology J260/01</p> <p>95 marks</p> <p>1 hour 45 minutes Written paper</p>	<p>26.4% of total GCSE</p>
	<p>Chemistry J260/02</p> <p>95 marks</p> <p>1 hour 45 minutes Written paper</p>	<p>26.4% of total GCSE</p>
	<p>Physics J260/03</p> <p>95 marks</p> <p>1 hour 45 minutes Written paper</p>	<p>26.4% of total GCSE</p>
	<p>Combined Science J260/04</p> <p>75 marks</p> <p>1 hour 45 minutes Written paper</p>	<p>20.8% of total GCSE</p>

Content Overview

Assessment Overview

Higher Tier, grades 4–4 to 9–9

Content is split into twenty teaching chapters:

- Chapter B1: You and your Genes
- Chapter B2: Keeping healthy
- Chapter B3: Living together – food and ecosystems
- Chapter B4: Using food and controlling growth
- Chapter B5: The human body – staying alive
- Chapter B6: Life on Earth – past, present and future
- Chapter C1: Air and water
- Chapter C2: Chemical patterns
- Chapter C3: Chemicals of the natural environment
- Chapter C4: Material choices
- Chapter C5: Chemical analysis
- Chapter C6: Making useful chemicals
- Chapter P1: Radiation and waves
- Chapter P2: Sustainable energy
- Chapter P3: Electric circuits
- Chapter P4: Explaining motion
- Chapter P5: Radioactive materials
- Chapter P6: Matter – models and explanations
- Chapter BCP7: Ideas about Science
- Chapter BCP8: Practical Skills

Paper 5 assesses content B1 – B6 and BCP7 and 8

Paper 6 assesses content C1 – C6 and BCP7 and 8

Paper 7 assesses content P1 – P6 and BCP7 and 8

Paper 8 assesses all content

Biology

J260/05

95 marks

1 hour 45 minutes

Written paper

26.4%
of total
GCSE

Chemistry

J260/06

95 marks

1 hour 45 minutes

Written paper

26.4%
of total
GCSE

Physics

J260/07

95 marks

1 hour 45 minutes

Written paper

26.4%
of total
GCSE

Combined Science

J260/08

75 marks

1 hour 45 minutes

Written paper

20.8%
of total
GCSE

2b. Content of GCSE (9–1) in Combined Science B (Twenty First Century Science) (J260)

Layout of specification content

The specification content is divided into twenty chapters. There are six chapters for each of biology, chemistry and physics that describe the science content to be taught and assessed. Chapter BCP7 describes the *Ideas about Science* that should be taught, and will be assessed in contexts taken from any of the preceding chapters. The *Ideas about Science* cover the requirements of *Working Scientifically*. The final chapter describes the requirements for practical skills.

In the specification, the content that is assessable is presented in two columns: the teaching and learning narrative and the assessable learning outcomes. The narrative summarises the science story and provides context for the assessable learning outcomes thereby supporting the teaching of the specification. The assessable learning outcomes

define the requirements for assessment and any contexts given in the narratives may also be assessed.

Within each chapter:

An overview summarises the science ideas included in the chapter, explaining why these ideas are relevant to learners living in the twenty first century and why it is desirable for learners to understand them.

Following the overview is a summary of the knowledge and understanding that learners should have gained from study at Key Stages 1 to 3. Some of these ideas are repeated in the content of the specification and while this material need not be retaught, it can be drawn upon to develop ideas at GCSE (9–1).

Learning at GCSE (9–1) is described in the tables that follow:

Teaching and learning narrative	Assessable learning outcomes	Linked learning opportunities
The teaching and learning narrative summarises the science story, including relevant <i>Ideas about Science</i> to provide contexts for the assessable learning outcomes. The narrative is intended to support teaching and learning. The requirements for assessment are defined by the assessable learning outcomes and any context given in the narrative may also be assessed.	<p>The assessable learning outcomes set out the level of knowledge and understanding that learners are expected to demonstrate. The statements give guidance on the breadth and depth of learning.</p> <p>Emboldened statements will only be assessed in Higher Tier papers.</p> <p>The mathematical requirements in Appendix 5d are referenced by the prefix M to link the mathematical skills required to the areas of science content where those mathematical skills could be linked to learning.</p> <p>Opportunities for carrying out practical activities are indicated throughout the specification and are referenced as <i>PAGB1</i> to <i>PAGP6</i> (Practical Activity Group; see Chapter BCP8).</p> <p>① <i>Advisory notes clarify the depth of cover required</i></p>	<p>The linked learning opportunities suggest ways to develop <i>Ideas about Science</i> and practical skills in context, and also highlight links to ideas in other chapters.</p> <p>Note, however, that <i>Ideas about Science</i> and practical skills may be taught, and will be assessed, in any context.</p>

The Assessment Objectives in Section 3b make clear the range of ways in which learners will be required to demonstrate their knowledge and understanding

in the assessments, and the Sample Assessment Materials (provided on the OCR website at www.ocr.org.uk) provide examples.

Biology key ideas

Biology is the science of living organisms (including animals, plants, fungi and microorganisms) and their interactions with each other and the environment.

The study of biology involves collecting and interpreting information about the natural world to identify patterns and relate possible cause and effect. Biological information is used to help humans improve their own lives and strive to create a sustainable world for future generations.

Learners should be helped to understand how, through the ideas of biology, the complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas which are of universal application, and which include:

- 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.

A summary of the content for the GCSE (9–1) Combined Science B (Twenty First Century Science) course is as follows:

Chapter B1: You and your genes	Chapter B2: Keeping healthy	Chapter B3: Living together – food and ecosystems
B1.1 What is the genome and what does it do? B1.2 How is genetic information inherited? B1.3 How can and should gene technology be used?	B2.1 What are the causes of disease? B2.2 How do organisms protect themselves against pathogens? B2.3 How can we prevent the spread of infection? B2.4 How can lifestyle, genes and the environment affect my health? B2.5 How can we treat disease?	B3.1 What happens during photosynthesis? B3.2 How do producers get the substances they need? B3.3 How are organisms in an ecosystem interdependent? B3.4 How are populations affected by conditions in an ecosystem?
Chapter B4: Using food and controlling growth	Chapter B5: The human body – staying alive	Chapter B6: Life on Earth – past, present and future
B4.1 What happens during cellular respiration? B4.2 How do we know about mitochondria and other cell structures? B4.3 How do organisms grow and develop? B4.4 Should we use stem cells to treat damage and disease?	B5.1 How do substances get into, out of and around our bodies? B5.2 How does the nervous system help us respond to changes? B5.3 How do hormones control responses in the human body? B5.4 Why do we need to maintain a constant internal environment? B5.5 What role do hormones play in human reproduction? B5.6 What can happen when organs and control systems stop working?	B6.1 How was the theory of evolution developed? B6.2 How does our understanding of biology help us classify the diversity of organisms on Earth? B6.3 How is biodiversity threatened and how can we protect it?

Chapter BCP7: Ideas about Science

- IaS1 What needs to be considered when investigating a phenomenon scientifically?
- IaS2 What conclusions can we make from data?
- IaS3 How are scientific explanations developed?
- IaS4 How do science and technology impact society?

Chapter BCP8: Practical Skills

Chemistry key ideas

Chemistry is the science of the composition, structure, properties and reactions of matter, understood in terms of atoms, atomic particles and the way they are arranged and link together. It is concerned with the synthesis, formulation, analysis and characteristic properties of substances and materials of all kinds.

Learners should be helped to appreciate the achievements of chemistry in showing how the complex and diverse phenomena of both the natural and man-made worlds can be described in terms of a small number of key ideas which are of universal application, and which include:

- matter is composed of tiny particles called atoms and there are about 100 different naturally occurring types of atoms called elements
- elements show periodic relationships in their chemical and physical properties
- these periodic properties can be explained in terms of the atomic structure of the elements
- atoms bond by either transferring electrons from one atom to another or by sharing electrons
- the shapes of molecules (groups of atoms bonded together) and the way giant structures are arranged is of great importance in terms of the way they behave
- there are barriers to reaction so reactions occur at different rates
- chemical reactions take place in only three different ways:
 - proton transfer
 - electron transfer
 - electron sharing
- energy is conserved in chemical reactions so can therefore be neither created or destroyed.

Chapter C1: Air and water	Chapter C2: Chemical patterns	Chapter C3: Chemicals of the natural environment
C1.1 How has the Earth's atmosphere changed over time, and why?	C2.1 How have our ideas about atoms developed over time?	C3.1 How are the atoms held together in a metal?
C1.2 Why are there temperature changes in chemical reactions?	C2.2 What does the Periodic Table tell us about the elements?	C3.2 How are metals with different reactivities extracted?
C1.3 What is the evidence for climate change, why is it occurring?	C2.3 How do metals and non-metals combine to form compounds?	C3.3 What are electrolytes and what happens during electrolysis?
C1.4 How can scientists help improve the supply of potable water?	C2.4 How are equations used to represent chemical reactions?	C3.4 Why is crude oil important as a source of new materials?
Chapter C4: Material choices	Chapter C5: Chemical analysis	Chapter C6: Making useful chemicals
C4.1 How is data used to choose a material for a particular use?	C5.1 How are chemicals separated and tested for purity?	C6.1 What useful products can be made from acids?
C4.2 How do bonding and structure affect properties of materials?	C5.2 How are the amounts of substances in reactions calculated?	C6.2 How do chemists control the rate of reactions?
C4.3 Why are nanoparticles so useful?	C5.3 How are amounts of chemicals in solution measured?	C6.3 What factors affect the yield of chemical reactions?
C4.4 What happens to products at the end of their useful life?		

Chapter BCP7: Ideas about Science

- laS1 What needs to be considered when investigating a phenomenon scientifically?
- laS2 What conclusions can we make from data?
- laS3 How are scientific explanations developed?
- laS4 How do science and technology impact society?

Chapter BCP8: Practical Skills

Physics key ideas

Physics is the science of the fundamental concepts of field, force, radiation and particle structures, which are inter-linked to form unified models of the behaviour of the material universe. From such models, a wide range of ideas, from the broadest issue of the development of the universe over time to the numerous and detailed ways in which new technologies may be invented, have emerged. These have enriched both our basic understanding of, and our many adaptations to, our material environment.

Learners should be helped to understand how, through the ideas of physics, the complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas which are of universal application and which include:

- 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.

Chapter P1: Radiation and waves	Chapter P2: Sustainable energy	Chapter P3: Electric circuits
<p>P1.1 What are the risks and benefits of using radiations?</p> <p>P1.2 What is climate change and what is the evidence for it?</p> <p>P1.3 How do waves behave?</p>	<p>P2.1 How much energy do we use?</p> <p>P2.2 How can electricity be generated?</p>	<p>P3.1 What determines the current in an electric circuit?</p> <p>P3.2 How do series and parallel circuits work?</p> <p>P3.3 What determines the rate of energy transfer in a circuit?</p> <p>P3.4 What are magnetic fields?</p> <p>P3.5 How do electric motors work?</p>
Chapter P4: Explaining motion	Chapter P5: Radioactive materials	Chapter P6: Matter – models and explanations
<p>P4.1 What are forces?</p> <p>P4.2 How can we describe motion?</p> <p>P4.3 What is the connection between forces and motion?</p> <p>P4.4 How can we describe motion in terms of energy transfers?</p>	<p>P5.1 What is radioactivity?</p> <p>P5.2 How can radioactive materials be used safely?</p>	<p>P6.1 How does energy transform matter?</p> <p>P6.2 How does the particle model explain the effects of heating?</p> <p>P6.3 How does the particle model relate to materials under stress?</p>

Chapter BCP7: Ideas about Science

- IaS1 What needs to be considered when investigating a phenomenon scientifically?
- IaS2 What conclusions can we make from data?
- IaS3 How are scientific explanations developed?
- IaS4 How do science and technology impact society?

Chapter BCP8: Practical Skills

2c. Content of chapters B1 to BCP8

Chapter B1: You and your genes

Overview

The inheritance of genetic information from each generation to the next is a fundamental idea in science; it can help us answer questions about why we look the way we do, and builds a foundation for later exploration of ideas about genetic diseases, cell division and growth, and evolution.

Topic B1.1 explores basic concepts of the genome and how it affects an organism's characteristics, through ideas about DNA and genes as the units of genetic information, the link between genes and proteins, and how the interaction between genes and the environment affects how an individual looks, develops and functions.

Topic B1.2 explores inheritance by considering the effects of dominant and recessive alleles, the inheritance of characteristics, the principles of inheritance of single-gene characteristics and how sex is determined.

Understanding of the genome and emerging gene technologies are at the cutting edge of science, and they promise powerful applications to benefit present and future generations. But they also present ethical issues for individuals and society. Topic B1.3 explores some of the ideas people use to make decisions about applications of gene technology including genetic testing and genetic engineering.

Learning about genes and inheritance before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- know that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents
- know that heredity is the process by which genetic information is transmitted from one generation to the next
- know that genetic information is stored in the nucleus
- understand a simple model of chromosomes, genes and DNA
- know about the part played by Watson, Crick, Wilkins and Franklin in the development of the DNA model
- know about sexual reproduction in animals, including the role of gametes and the process of fertilisation
- know about sexual and asexual reproduction in plants, including flower structures and the processes of pollination and fertilisation.

Tiering

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

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

Learning about genes and inheritance at GCSE (9–1)

B1.1 What is the genome and what does it do?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>All organisms contain genetic material. Genetic material contains instructions that control how cells and organisms develop and function. Most of an organism's characteristics depend on these instructions and are modified by interaction with the environment.</p> <p>Genetic material in plant and animal cells is located in the nucleus, one of the main sub-cellular structures. In organisms whose cells do not have a nucleus (e.g. bacteria) the genetic material is located in the cytoplasm.</p> <p>All the genetic material of a cell is the organism's genome. In most organisms the genome is packaged into chromosomes. Chromosomes are long molecules of DNA. Genes are sections of this DNA.</p> <p>In the cells of plants and animals, chromosomes occur in pairs. The two chromosomes in a pair each carry the same genes. The two versions of each gene in the pair are called alleles, and can be the same or different. A different version of a gene is a genetic variant. The genotype of an organism is the combination of alleles it has for each gene; the phenotype is the characteristic that results from this combination and interaction with the environment. Genes tell a cell how to make proteins by joining together amino acids in a particular order.</p>	<p>1. a) explain how the nucleus and genetic material of eukaryotic cells (plants and animals) and the genetic material, including plasmids, of prokaryotic cells are related to cell functions</p> <p>b) describe how to use a light microscope to observe a variety of plant and animal cells</p>
	2. describe the genome as the entire genetic material of an organism
	3. describe DNA as a polymer made up of nucleotides, forming two strands in a double helix
	4. describe simply how the genome and its interaction with the environment influence the development of the phenotype of an organism, including the idea that most characteristics depend on instructions in the genome and are modified by interaction of the organism with its environment ① <i>Learners are not expected to describe epigenetic effects</i>
	5. explain the terms chromosome, gene, allele, variant, genotype and phenotype
	6. explain the importance of amino acids in the synthesis of proteins, including the genome as instructions for the polymerisation of amino acids to make proteins

Linked learning opportunities

Practical work:

- Use a microscope to look at a variety of plant and animal cells.
- Extract DNA from plant tissue.

Specification links:

- Principles of polymerisation, and DNA and proteins as examples of polymers (C4.2).

B1.2 How is genetic information inherited?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>During sexual reproduction, each offspring inherits two alleles of each gene; one allele from each gamete. The two alleles can be two copies of the same genetic variant (homozygous) or different variants (heterozygous). A variant can be dominant or recessive, and the combination of alleles determines what effect the gene has.</p> <p>Genetic diagrams such as family trees and Punnett squares can be used to model and predict outcomes of the inheritance of characteristics that are determined by a single gene (1aS3). However, most characteristics depend on the instructions in multiple genes and other parts of the genome.</p>	1. explain the terms gamete, homozygous, heterozygous, dominant and recessive
	2. explain single gene inheritance, including dominant and recessive alleles and use of genetic diagrams
	3. predict the results of single gene crosses
	4. use direct proportions and simple ratios in genetic crosses M1c
	5. use the concept of probability in predicting the outcome of genetic crosses M2e
	6. recall that most phenotypic features are the result of multiple genes rather than single gene inheritance <i>① Learners are not expected to describe epistasis and its effects</i>
A human individual's sex is determined by the inheritance of genes located on sex chromosomes; specifically, genes on the Y chromosome trigger the development of testes.	7. describe sex determination in humans

Linked learning opportunities

Practical work:

- Microscopy of pollen tubes on agar (nuclei visible under high power).

Ideas about Science:

- Use genetic diagrams (e.g. family trees and Punnett squares) to model and predict outcomes of single gene inheritance (1aS3).

B1.3 How can and should gene technology be used?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Comparing the genomes of individuals with and without a disease can help to identify alleles associated with the disease. Once identified, we can test for these alleles in adults, children, fetuses and embryos, to investigate their risk of developing certain diseases. We can also assess the risk of adults passing these alleles to their offspring (including the identification of ‘carriers’ of recessive alleles). Genetic testing can also help doctors to prescribe the correct drugs to a patient (‘personalised medicine’), by testing for alleles that affect how drugs will work in their body.</p> <p>Another application of gene technology is genetic engineering, in which the genome is modified to change an organism’s characteristics. Genetic engineering has been used to introduce characteristics useful to humans into organisms such as bacteria and plants.</p> <p>Gene technology could help us provide for the needs of society, by improving healthcare and producing enough food for the growing population. But with genetic testing we must also consider how the results will be used and by whom, and the risks of false positives/negatives and miscarriage (when sampling amniotic fluid). With genetic engineering there are concerns about the spread of inserted genes to other organisms, the need for long-term studies to check for adverse reactions, and moral concerns about modifying genomes and the application of the technology to modify humans (1aS4).</p>	<ol style="list-style-type: none"> 1. discuss the potential importance for medicine of our increasing understanding of the human genome, including the discovery of alleles associated with diseases and the genetic testing of individuals to inform family planning and healthcare 2. describe genetic engineering as a process which involves modifying the genome of an organism to introduce desirable characteristics 3. describe the main steps in the process of genetic engineering including: <ul style="list-style-type: none"> • isolating and replicating the required gene(s) • putting the gene(s) into a vector (e.g. a plasmid) • using the vector to insert the gene(s) into cells • selecting modified cells 4. explain some of the possible benefits and risks, including practical and ethical considerations, of using gene technology in modern agriculture and medicine

Linked learning opportunities

Specification links:

- The involvement of genetic and other risk factors in the development of diseases such as cardiovascular disease, cancer and type 2 diabetes (B2.5).
- How can we treat disease? (B2.5).

Ideas about Science:

- Genetic testing and genetic engineering as applications of science that have made a positive difference to people’s lives (1aS4).
- Discuss risks, benefits, ethical issues and regulation associated with gene technology (1aS4).

Chapter B2: Keeping healthy

Overview

Issues of risk, ethics and social responsibility related to disease prevention and treatment in humans and plants are often in the news. Understanding the science of health and disease enables us to consider the issues critically, and to explore possible answers.

In Topic B2.1, learners explore how different pathogens are spread and cause disease, with reference to some common communicable diseases of humans and plants, then in Topic B2.2 they consider how the immune system in humans protects against infection.

Topic B2.3 looks at ways in which individuals and society can reduce the spread of diseases, linked to issues of risk and decision making, for example with regard to vaccination and contraception.

In Topic B2.4 the way that lifestyle and genetic factors increase (or decrease) the risk of developing non-communicable diseases is explored, with reference to ideas about correlation and cause. Finally, learners learn about ways of treating diseases in Topic B2.5 and explore issues related to the development and testing of new treatments.

Learning about health and disease before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- appreciate that good hygiene helps humans keep healthy
- be able to identify and name the main parts of the human circulatory system, and describe the functions of the heart, blood vessels and blood
- appreciate the importance of bacteria in the human digestive system
- know that animals, including humans, need the right types and amount of nutrition, and that a healthy human diet includes carbohydrates, lipids (fats and oils), proteins, vitamins, minerals, dietary fibre and water
- recall some of the consequences of imbalances in the diet, including obesity, starvation and deficiency diseases
- recognise the impact of diet, exercise, drugs and lifestyle on the way their bodies function
- recall some of the effects of recreational drugs (including substance misuse) on behaviour, health and life processes.

Tiering

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

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

Learning about health and disease at GCSE (9–1)

B2.1 What are the causes of disease?	
Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The health of most organisms will be compromised by disease during their lifetime. Physical and mental health can be compromised by disease caused by infection by a pathogen, an organism's alleles or lifestyle, or trauma. Disease damages host cells and impairs functions, causing symptoms. However, an unhealthy organism may not always show symptoms of disease, particularly during the 'incubation period' after infection with a pathogen.</p> <p>Some diseases are communicable: they are caused by pathogenic bacteria, viruses, protists and fungi, and can be spread from organism to organism in bodily fluids, on surfaces, and in food and water. Other diseases are non-communicable: they are caused by genetic and/or lifestyle factors and cannot be spread from one organism to another.</p> <p>Some common diseases illustrate different types of pathogen and common routes of spread and infection, including:</p> <p>In humans: influenza (viral), <i>Salmonella</i> food poisoning (bacterial), Athlete's foot (fungal), malaria (protist) and HIV (viral STI).</p> <p>In plants: tobacco mosaic virus (viral), ash dieback (fungal) and crown gall disease (bacterial).</p>	1. describe the relationship between health and disease
	2. describe different types of diseases (including communicable and non-communicable diseases)
	3. explain how communicable diseases (caused by viruses, bacteria, protists and fungi) are spread in animals and plants
	4. describe common human infections including influenza (viral), <i>Salmonella</i> (bacterial), Athlete's foot (fungal) and malaria (protist) and sexually transmitted infections in humans including HIV/AIDS (viral)
	5. describe plant diseases including tobacco mosaic virus (viral), ash dieback (fungal) and crown gall disease (bacterial)

Linked learning opportunities

Practical work:

- Model the spread of infection using liquids (where one is 'infected' with an invisible chemical that can be detected experimentally).
- Culture and microscopy of swabs from different surfaces.

B2.2 How do organisms protect themselves against pathogens?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Humans have physical, chemical and microbial defences that make it difficult for pathogens to enter the blood. These include the skin and mucus, stomach acid, saliva, tears, and bacteria in the gut.	1. describe non-specific defence systems of the human body against pathogens, including examples of physical, chemical and microbial defences
These defences are always present, and are not produced in response to any specific pathogen. Platelets help to seal wounds to reduce the chance of pathogens entering the blood.	2. explain how platelets are adapted to their function in the blood
The immune system of the human body works to protect us against disease caused by pathogens.	3. explain the role of the immune system of the human body in defence against disease
If a pathogen enters the blood, white blood cells destroy it. White blood cells have receptors that bind to antigens on pathogens, to distinguish between non-self and self. Different types of white blood cell are adapted to either ingest and digest pathogens, or release chemicals that break them down, or produce antibodies to disable them or tag them for attack by other white blood cells. An antibody is specific for (only binds to) a particular antigen. Once the body has made antibodies against a pathogen, memory cells stay in the body to make antibodies quickly upon re-infection (immunity).	4. explain how white blood cells are adapted to their functions in the blood, including what they do and how it helps protect against disease

Linked learning opportunities

B2.3 How can we prevent the spread of infection?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Reducing and preventing the spread of communicable diseases in animals and plants helps prevent loss of life, destruction of habitats and loss of food sources. For plants, strategies include regulating the movement of plant material, sourcing healthy plants and seeds, destroying infected plants, polyculture, crop rotation and chemical and biological control. For animals, including humans, strategies include vaccination (to establish immunity), contraception, hygiene, sanitation, sterilising wounds, restricting travel, and destruction of infected animals.</p> <p>The likely effectiveness, benefits, risks and cost of each strategy must be considered, and an individual's right to decide balanced with what is best for society (IaS4).</p>	<ol style="list-style-type: none"> 1. explain how the spread of communicable diseases may be reduced or prevented in animals and plants, to include a minimum of one common human infection, one plant disease and sexually transmitted infections in humans including HIV/AIDS 2. explain the use of vaccines in the prevention of disease, including the use of safe forms of pathogens and the need to vaccinate a large proportion of the population

Linked learning opportunities

Practical work:

- Investigate microbial growth on different foods and surfaces in different conditions.

Ideas about Science:

- Discuss risk and decision making in the context of disease prevention (IaS4).

B2.4 How can lifestyle, genes and the environment affect health?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Whether or not a person develops a non-communicable disease depends on many factors, including the alleles they inherited and aspects of their lifestyle. The interaction of genetic and lifestyle factors can increase or decrease the risk.</p>	<p>1. a) describe how the interaction of genetic and lifestyle factors can increase or decrease the risk of developing non-communicable human diseases, including cardiovascular diseases, many forms of cancer, some lung and liver diseases and diseases influenced by nutrition, including type 2 diabetes</p> <p>b) describe how to practically investigate the effect of exercise on pulse rate and recovery rate</p>
	<p>2. use given data to explain the incidence of non-communicable diseases at local, national and global levels with reference to lifestyle factors, including exercise, diet, alcohol and smoking</p>
	<p>3. in the context of data related to the causes, spread, effects and treatment of disease:</p> <p>a) translate information between graphical and numerical forms M4a</p> <p>b) construct and interpret frequency tables and diagrams, bar charts and histograms M4a, M4c</p> <p>c) understand the principles of sampling as applied to scientific data M2d</p> <p>d) use a scatter diagram to identify a correlation between two variables M2g</p>
	<p>4. describe interactions between different types of disease</p>
<p>Different types of disease can interact, such as when having a disease increases or decreases the risk of developing or contracting another.</p>	

Linked learning opportunities

Specification links:

- What causes cancer (B4.3).
- Diseases caused by genes (B1.2/3).

Practical work:

- Investigate the amounts of fat and sugar in foods/drinks.
- Measure blood pressure, recovery rate.

Ideas about Science:

- Discuss correlation, cause and risk in the context of non-communicable diseases (IaS3, IaS4).

B2.5 How can we treat disease?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Humans have developed medicines, including antibiotics, which can control or eliminate the cause of some diseases and/or reduce the length or severity of symptoms.</p> <p>For non-communicable diseases such as cardiovascular disease, strategies that lower the risk of developing the disease have benefits compared to treatments administered later.</p> <p>Many factors need to be considered when prescribing treatments, including the likely effectiveness, risk of adverse reactions, patient consent, and the costs and benefits to the patient and others (1aS4).</p> <p>Studying the genomes and proteins of pathogens and host cells can suggest targets for new medicines. Large libraries of chemicals are screened for their ability to affect a target. It is unlikely that a perfect medicine will be found during screening, but chemicals are selected for modification and further tests.</p> <p>All new medicines have to be tested before they are made widely available. Preclinical testing, for safety and effectiveness, uses animals and cultured human cells. Clinical testing uses healthy human volunteers to test for safety, and humans with the disease to test for safety and effectiveness. ‘Open-label’, ‘blind’ and ‘double-blind’ trials can be used. There are ethical questions around using placebos in tests on people with a disease (1aS4).</p>	<ol style="list-style-type: none"> 1. explain the use of medicines in the treatment of disease 2. calculate cross-sectional areas of bacterial cultures and of clear zones around antibiotic discs on agar jelly using πr^2 M5c PAGB5 3. evaluate different strategies for lowering the risk of cardiovascular disease and treating it, including lifestyle changes, use of medicines and surgery 4. describe the process of discovery and development of potential new medicines including preclinical and clinical testing

Linked learning opportunities

Specification links:

- ‘Personalised medicine’ (B1.3).
- Antibiotic resistance in microorganisms (B6.1).

Ideas about Science:

- Risk and decision making in the context of medicines and treatment (1aS4).

Ideas about Science:

- Ethics in the context of using placebos in clinical testing of new medicines (1aS4).

Chapter B3: Living together – food and ecosystems

Overview

All living organisms depend on the ability of photosynthetic organisms to synthesise glucose from carbon dioxide and water in the presence of light, and on feeding relationships to transfer biomass through communities.

From study at earlier Key Stages, learners will be familiar with the reactants and products of photosynthesis, and the need for light in the process. In Topics B3.1 and B3.2 the context of photosynthesis is used to explore several fundamental concepts in

biology, including enzyme action and the movement of chemicals by diffusion, osmosis and active transport.

Learners expand their knowledge of the interdependencies between organisms within ecosystems in Topic B3.3, through understanding of food webs, competition for resources, and the cycling of chemicals.

Finally, Topic B3.4 considers the effects that environmental changes and human activities can have on interacting populations within ecosystems.

Learning about food and ecosystems before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- understand the similarities and differences between plant and animal cells
- know that some organisms make their own food using photosynthesis
- know that photosynthesis in plant cells occurs in the chloroplasts
- know the reactants in, and products of, photosynthesis, and be able to write a word summary
- know that photosynthesis requires light
- be familiar with the adaptations of leaves for photosynthesis, and the role of stomata in gas exchange
- know that water and minerals enter a plant through the roots
- know that molecules of a solute move through solvent, and through cell membranes, by diffusion
- know that animals obtain their food from plants (and other animals that ate plants)
- understand the difference between carnivores, herbivores and omnivores, and between producers and consumers
- know that individuals of the same type living in the same place make up a population, and that all the interacting populations in an ecosystem make up the community
- understand the use of food chains and food webs as models of the feeding relationships within a community
- appreciate the interdependence of organisms in a community, including food webs, the breakdown and cycling of materials, and animals as pollinators
- know that changes in an ecosystem can affect the survival of individuals and populations.

Tiering

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

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

Learning about food and ecosystems at GCSE (9–1)

B3.1 What happens during photosynthesis?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Producers make glucose using photosynthesis. Some of the glucose is used as the fuel for cellular respiration, some is converted into starch and then stored, and the rest is combined with elements absorbed from the environment to make carbohydrates, lipids and proteins (biomass) for growth.	1. a) describe the process of photosynthesis, including the inputs and outputs of the two main stages and the requirement of light in the first stage, and describe photosynthesis as an endothermic process b) describe practical investigations into the requirements and products of photosynthesis <i>PAGB4</i>
Photosynthesis involves many chemical reactions, but can be summarised in two main stages. The first stage requires light and chlorophyll (located in chloroplasts in plant cells) to split water molecules into hydrogen and oxygen. The hydrogen is transferred to the second stage, but the oxygen is released into the atmosphere as a waste product. The second stage combines carbon dioxide with hydrogen to make glucose.	2. explain how chloroplasts in plant cells are related to photosynthesis
The reactions in photosynthesis and many other biological processes are catalysed by enzymes.	3. a) explain the mechanism of enzyme action including the active site, enzyme specificity and factors affecting the rate of enzyme catalysed reactions, including substrate concentration, temperature and pH b) describe practical investigations into the effect of substrate concentration, temperature and pH on the rate of enzyme controlled reactions <i>M2b, M2f, M3d, M4a, M4b, M4c</i> <i>PAGB3</i>
The lock and key model can be used to explain enzyme action, and to make predictions about and explain the effects on the rate of enzyme-catalysed reactions when the substrate concentration, temperature and pH are changed (IaS3).	

Linked learning opportunities

Practical work:

- On a whole plant, wrap one leaf in foil, and enclose another leaf in a conical flask with a small amount of KOH (to remove CO₂); after 24 h, test leaves for starch.

Practical work:

- Investigate effects of substrate concentration, temperature and pH on enzyme activity.

Ideas about Science:

- Lock and key model to explain and make predictions about enzyme activity (IaS3).

B3.1 What happens during photosynthesis?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Understanding of how factors affect enzyme activity helps to explain the effects of temperature and carbon dioxide concentration on the rate of photosynthesis. The effect of light intensity is explained by the need for light to bring about reactions in photosynthesis. Light intensity is inversely proportional to the square of the distance from the light source (the inverse square law); this helps to explain why the rate of photosynthesis changes with distance from a point light source.</p>	<p>4. a) explain the effect of temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis</p> <p>b) describe practical investigations into the effect of environmental factors on the rate of photosynthesis PAGB4</p>
	<p>5. use the inverse square law to explain why the rate of photosynthesis changes with distance from a light source</p>
	<p>6. explain the interaction of temperature, light intensity and carbon dioxide concentration in limiting the rate of photosynthesis, and use graphs depicting the effects</p>
	<p>7. in the context of the rate of photosynthesis:</p> <p>a) understand and use simple compound measures such as the rate of a reaction M1a, M1c</p> <p>b) translate information between graphical and numerical form M4a</p> <p>c) plot and draw appropriate graphs selecting appropriate scales for axes M4a, M4c</p> <p>d) extract and interpret information from graphs, charts and tables M2c</p>

Linked learning opportunities

Practical work:

- Investigate rate of photosynthesis by collecting gas or counting bubbles from pondweed.
- Use a datalogger to measure oxygen concentration, pH, temperature and light intensity over 24 h for pondweed

B3.2 How do producers get the substances they need?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The ways in which photosynthetic organisms take in carbon dioxide and water for photosynthesis, and release the waste product oxygen, illustrate the principles of diffusion and osmosis. Generally, molecules move from a region of their higher concentration to a region of their lower concentration; the difference in concentration drives a change towards equal concentration. Carbon dioxide and oxygen molecules move by diffusion, through cell membranes in single-cellular (prokaryotic) producers, and through stomata and cell membranes in plants. Water molecules move by osmosis through cell membranes; projections from root cells ('root hairs') of plants increase the surface area for osmosis.</p> <p>The way in which photosynthetic organisms take in nitrogen (to make proteins) illustrates the process of active transport. Producers get nitrogen from nitrate ions (NO_3^-). Molecules of water and gases can diffuse through partially-permeable cell membranes but nitrate ions cannot; producers use energy from molecules of ATP to transport nitrate ions through the cell membrane by active transport.</p> <p>Plants do not have blood to transport substances around the organism; they have transport vessels formed from xylem and phloem.</p> <p>Water and ions (e.g. nitrate) in aqueous solution are moved through xylem from the roots and up the stem/trunk by transpiration, to replace water that evaporates from open stomata.</p>	<ol style="list-style-type: none"> describe some of the substances transported into and out of photosynthetic organisms in terms of the requirements of those organisms, including oxygen, carbon dioxide, water and mineral ions <ol style="list-style-type: none"> explain how substances are transported into and out of cells through diffusion, osmosis and active transport describe practical investigations into the processes of diffusion and osmosis <p>① <i>Learners are not expected to explain osmosis in terms of water potential</i></p> explain how the partially permeable cell membranes of plant cells and prokaryotic cells are related to cell functions explain how water and mineral ions are taken up by plants, relating the structure of the root hair cells to their function <ol style="list-style-type: none"> explain how the structure of the xylem and phloem are adapted to their functions in the plant describe how to use a light microscope to observe the structure of the xylem and phloem <p><i>PAGB1</i></p>

Linked learning opportunities

Practical work:

- Investigate diffusion using drops of ink in water and in agar in Petri dishes on graph paper.
- Investigate diffusion across a partially permeable membrane using starch suspension in dialysis tubing in a beaker of water; compare adding iodine solution inside versus outside the tubing.
- Investigate the effect of solute concentration on osmosis using potato cylinders in sugar solution.

Practical work:

- Use eosin stain to observe xylem in broad bean plant stem under hand lens and microscope.

B3.2 How do producers get the substances they need?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Sugars are moved through phloem from photosynthetic to non-photosynthetic tissues by translocation. Sugars are loaded into phloem by active transport, then water moves into the concentrated solution by osmosis and pushes the substances along the tube.</p> <p>The rate of water uptake by a plant can be affected by environmental factors. Light intensity and temperature affect the rate of photosynthesis (and therefore the demand for water), while air movement and temperature affect the rate of water loss from aerial parts of the plant.</p>	<p>6. a) describe the processes of transpiration and translocation, including the structure and function of the stomata</p> <p>b) describe how to use a light microscope to observe the structure of stomata <i>PAGB1</i></p> <p>c) describe how to use a simple potometer</p> <p>① <i>Learners are not expected to describe transpiration in terms of tension or pressure, and are not expected to describe translocation in terms of water potential or hydrostatic pressure</i></p>
	<p>7. a) explain the effect of a variety of environmental factors on the rate of water uptake by a plant, to include light intensity, air movement, and temperature</p> <p>b) describe practical investigations into the effect of environmental factors on the rate of water uptake by a plant</p>
	<p>8. in the context of water uptake by plants:</p> <p>a) use simple compound measures such as rate M1a, M1c</p> <p>b) carry out rate calculations M1a, M1c</p> <p>c) plot, draw and interpret appropriate graphs M4a, M4b, M4c, M4d</p> <p>d) calculate percentage gain and loss of mass M1c</p>

Linked learning opportunities

- Observe stomata (paint two thin layers of nail varnish onto a leaf, put clear tape over then peel off, stick to microscope slide).

B3.3 How are organisms in an ecosystem interdependent?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Producers take in carbon and nitrogen compounds from their environment and use them (along with oxygen, hydrogen and other elements) to make small organic molecules including sugars, fatty acids, glycerol and amino acids. These small molecules are used to make larger organic molecules, such as long-chain carbohydrates, lipids and proteins. The larger molecules are used to build new structures (e.g. membranes, organelles).	1. a) explain the importance of sugars, fatty acids and glycerol, and amino acids in the synthesis and breakdown of carbohydrates, lipids and proteins b) describe the use of qualitative tests for biological molecules
Consumers can only get their supply of carbon and nitrogen compounds by eating producers (or other consumers that ate producers) and digesting the biomass. This releases the small molecules so they can be absorbed and then used to build biomass in the consumer.	2. describe photosynthetic organisms as the main producers of food and therefore biomass for life on Earth
The transfer of biomass between organisms is one way in which the populations in a community are interdependent, and can be modelled using a food web (1aS3).	3. describe some of the substances transported into organisms in terms of the requirements of those organisms, including dissolved food molecules
The size of each population in a community is limited by predation and competition for food and other resources including space, water, light, shelter, mates, pollinators and seed dispersers.	4. describe different levels of organisation in an ecosystem from individual organisms to the whole ecosystem
Substances essential to life, including water and carbon, cycle through the biotic and abiotic components of ecosystems so that they can be used and reused by organisms. Water cycles through precipitation, food chains, transpiration, excretion, run-off, flow through streams/rivers/oceans, and evaporation. Carbon cycles through photosynthesis, food chains, cellular respiration, decomposition and combustion. Decomposition is catalysed by enzymes released by microorganisms.	5. explain the importance of interdependence and competition in a community
	6. recall that many different substances cycle through the abiotic and biotic components of an ecosystem
	7. explain the importance of the carbon cycle and the water cycle to living organisms
	8. explain the role of microorganisms in the cycling of substances through an ecosystem
	9. calculate the percentage of mass, in the context of the use and cycling of substances in ecosystems M1c

Linked learning opportunities

Practical work:

- Investigate the break down of starch into sugars using amylase and test strips.

Ideas about Science:

- Use a food web as a model to explain interdependence in a community, identify limitations of the model, and use it to make predictions about the effects that a change in the ecosystem could have on the interacting populations (1aS3).

Practical work:

- Culture microorganisms on starch agar, stain with iodine solution; clear areas beyond cultures show digestion by extracellular amylase.

B3.4 How are populations affected by the conditions in an ecosystem?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The distribution and abundance of organisms in an ecosystem depends on abiotic and biotic factors. The size of one or more populations in a community may be affected if the environmental conditions change, or if a new substance, competitor, predator or pathogen is introduced. A substance can bioaccumulate in a food chain to toxic concentration, and some can cause eutrophication. A change in the size of a population will affect other populations in the same community.</p> <p>The distribution and abundance of organisms, and changing conditions, within an ecosystem can be investigated using techniques including: identification keys; transects and quadrats; capture, mark, release and recapture; sampling living indicators; and using instruments to measure abiotic factors such as temperature, light intensity, soil moisture and pH.</p>	<p>1. explain how some abiotic and biotic factors affect communities, including environmental conditions, toxic chemicals, availability of food and other resources, and the presence of predators and pathogens</p>
	<p>2. describe how to carry out a field investigation into the distribution and abundance of organisms in an ecosystem and explain how to determine their numbers in a given area M2d PAGB2</p>
	<p>3. in the context of data related to organisms within a population:</p> <ul style="list-style-type: none"> a) calculate arithmetic means M2b, M2f b) understand and use percentiles M1c c) plot and draw appropriate graphs selecting appropriate scales for the axes M4a, M4c d) extract and interpret information from charts, graphs and tables M2c

Linked learning opportunities

Practical work:

- Investigate the distribution and abundance of organisms in an ecosystem.

Chapter B4: Using food and controlling growth

Overview

All living organisms depend on molecules of glucose obtained from photosynthesis (or from biomass obtained through food chains that start with photosynthetic organisms). The glucose is used for cellular respiration and in the synthesis of larger organic molecules used for growth.

From study at earlier Key Stages, learners will be familiar with the reactants and products of cellular respiration. In Topic B4.1 they explore how cellular respiration increases the amount of energy associated with cellular energy stores, in particular molecules of ATP that are essential for many life processes. In Topic B4.2 they consider briefly how we came to know what we do about organelles such as

mitochondria, using the context of electron microscopy to illustrate the idea that some scientific explanations were only developed once a technological development made certain observations possible.

Topic B4.3 links growth in multicellular organisms to the division of cells during the cell cycle, and explores the nature of stem cells and the role of cell differentiation. As a development of ideas, learners consider how cancer results from changes in DNA that cause a loss of control of cell division.

Finally, Topic B4.4 explores the question of whether stem cells should be used to regenerate tissue and treat disease.

Learning about cellular respiration and growth before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be familiar with the processes of aerobic and anaerobic respiration in living organisms, and fermentation in microorganisms, including word summaries of the reactions
- be able to recall the differences between aerobic and anaerobic respiration in terms of the reactants, products and implications for the organism
- be familiar with the tissues and organs of the human digestive system, including adaptations to function
- understand in simple terms that the human digestive system uses chemicals (including enzymes) to digest food
- appreciate the importance of bacteria in the human digestive system
- know how nutrients and water are transported within animals, including humans.

Tiering

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

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

Learning about cellular respiration and growth at GCSE (9–1)

B4.1 What happens during cellular respiration?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Consumers gain biomass from other organisms when they eat them. Some of this biomass is converted into molecules of glucose, the fuel for cellular respiration.</p> <p>Cellular respiration involves many chemical reactions and makes molecules of ATP. It occurs in the cytoplasm and mitochondria of animal and plant cells, and in the cytoplasm of microorganisms. ATP is required for processes that are essential for life, including breakdown and synthesis of molecules, active transport and muscle contraction.</p> <p>Aerobic respiration breaks down glucose and combines the breakdown products with oxygen, making water and carbon dioxide (a waste product).</p> <p>In conditions of low or no oxygen (such as in human cells during vigorous exercise, plant root cells in waterlogged soil and bacteria in puncture wounds) anaerobic respiration occurs. There is a partial breakdown of glucose, producing fewer molecules of ATP. In animal cells and some bacteria, this produces lactic acid (a waste product). In plants and some microorganisms, including yeast, it produces ethanol and carbon dioxide.</p>	1. compare the processes of aerobic and anaerobic respiration, including conditions under which they occur, the inputs and outputs, and comparative yields of ATP
	2. explain why cellular respiration occurs continuously in all living cells
	3. explain how mitochondria in eukaryotic cells (plants and animals) are related to cellular respiration
	4. describe cellular respiration as an exothermic process
	5. a) describe practical investigations into the effect of different substrates on the rate of respiration in yeast (PAG B4) b) carry out rate calculations for chemical reactions in the context of cellular respiration M1a, M1c

Linked learning opportunities

Practical work:

- Investigate the amount of energy released from different foods, by burning them under a boiling tube of water where:
 $\text{energy (kJ)} = \text{mass of water (kg)} \times \text{change in temperature (}^{\circ}\text{C)} \times 4.2 \text{ kJ/kg(}^{\circ}\text{C)}.$
- Investigate respiration in microorganisms by collecting CO_2 given off; which substrate works best?

B4.2 How do we know about mitochondria and other cell structures?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Scientific progress often relies on technological developments which enable new observations to be made. The invention of the electron microscope enabled us to observe cell organelles such as mitochondria and chloroplasts at much higher magnification than had previously been possible with light microscopes, and thus to develop explanations about how their structures relate to their roles in cellular processes (1aS3).	1. explain how electron microscopy has increased our understanding of sub-cellular structures
	2. in the context of cells and sub-cellular structures: <ul style="list-style-type: none"> a) demonstrate an understanding of number, size and scale and the quantitative relationship between units M2a, M2h b) use estimations and explain when they should be used M1d c) calculate with numbers written in standard form M1b

Linked learning opportunities

Ideas about Science:

- Explanations about the roles of cell organelles were developed from observations that could only be made using electron microscopy (1aS3).

B4.3 How do organisms grow and develop?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Growth of multicellular organisms involves an increase in the number of body cells. All new cells are created from existing cells when they divide. New body cells are created as part of the cell cycle. During interphase the cell grows larger, the numbers of organelles increase, and each chromosome is copied; then during mitosis the chromosome copies separate, the nucleus divides, and the cell divides to produce two new cells that are genetically identical to one another.</p> <p>Cancer is a non-communicable disease in humans caused by changes in a person's DNA. The changes cause a cell to divide many times by mitosis, which can create a tumour.</p> <p>Gametes are produced by meiosis, a different type of cell division. After interphase (during which the chromosome number has doubled), two meiotic divisions occur. Gametes contain half the number of chromosomes found in body cells (one chromosome from each pair). At fertilisation, maternal and paternal chromosomes pair up, so the zygote has the normal chromosome number.</p> <p>A zygote divides by mitosis to form an embryo. All of the cells in an embryo are initially identical and unspecialised; these are embryonic stem cells, and can become specialised to form any type of cell (differentiation) by switching genes off and on. Most cells in a human embryo become specialised after the eight cell stage. However, some (adult stem cells) remain unspecialised and can become specialised later to become many, but not all, types of cells.</p> <p>In plants, only cells in meristems undergo mitosis, producing unspecialised cells that can develop into any kind of plant cell.</p>	<ol style="list-style-type: none"> <ol style="list-style-type: none"> describe the role of the cell cycle in growth, including interphase and mitosis describe how to use a light microscope to observe stages of mitosis <i>PAGB1</i> <p>① <i>Learners are not expected to recall intermediate phases</i></p> describe cancer as the result of changes in cells that lead to uncontrolled growth and division explain the role of meiotic cell division in halving the chromosome number to form gametes, including the stages of interphase and two meiotic divisions ① <i>Learners are not expected to recall intermediate phases</i> describe the function of stem cells in embryonic and adult animals and meristems in plants explain the importance of cell differentiation, in which cells become specialised by switching genes off and on to form tissues with particular functions

Linked learning opportunities

Practical work:

- Investigate mitosis using a microscope to look at stained cells from onion root tip.

Specification links:

- Factors that increase the risk of developing cancer (B2.4).

B4.4 Should we use stem cells to treat damage and disease?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Stem cells offer the potential to treat patients by replacing damaged tissues or cells. But the benefits must be weighed against risks and ethical concerns about the use and destruction of human embryos to collect embryonic stem cells. For these reasons, use of stem cells in research and medicine is subject to government regulation in many countries (IaS4).</p>	<ol style="list-style-type: none"> 1. discuss potential benefits, risks and ethical issues associated with the use of stem cells in medicine

Linked learning opportunities

Ideas about Science:

- Stem cell therapy as an application of science that could change lives (IaS4).
- Risks, benefits and ethical issues associated with use of stem cells in medicine (IaS4).

Chapter B5: The human body – staying alive

Overview

From previous study, learners should appreciate that cells work together in multi-cellular organisms – in a hierarchy of cells, tissues, organs and systems – to support the functioning of each cell and of the organism as a whole. This chapter develops understanding of how cells and systems work together to support life in the human body.

In Topic B5.1, learners consider how the substances essential for chemical reactions are transported into, out of and around the human body, and why exchange surfaces are necessary.

In Topics B5.2 and B5.3 they explore how the nervous and endocrine systems help the body to detect and respond to external and internal changes. Topic B5.4 illustrates the importance of maintaining a constant internal environment.

The essential role of hormones in human reproduction is explored in Topic B5.5, followed in Topic B5.6 by consideration of what can happen when certain structures and systems – including the regulation of blood sugar, structures in the eye and neurons in the nervous system – go wrong.

Learning about the human body before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- appreciate the hierarchical organisation of multicellular organisms: from cells to tissues to organs to systems to organisms
- be able to identify, name, draw and label the basic parts of the human body
- have a basic understanding of the function of muscles
- be familiar with the tissues and organs of the human digestive system, including adaptations to function
- understand the basic structures and functions of the gas exchange system in humans, including adaptations to function
- understand the mechanism of breathing to move air in and out of the lungs, and be able to use a pressure model to explain the movement of gases
- understand, in outline, how nutrients and water are transported within animals, including humans
- be able to identify and name the main parts of the human circulatory system
- be familiar with the functions of the heart, blood vessels and blood
- know which part of the body is associated with each sense.

Tiering

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

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

Learning about the human body at GCSE (9–1)

B5.1 How do substances get into, out of and around our bodies?	
Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Oxygen, water and molecules from food are essential for chemical reactions in cells in the human body, including cellular respiration and synthesis of biomass. Carbon dioxide and urea are waste products that need to be removed from cells before they reach toxic levels. Moving these substances into, around and out of the body depends upon interactions between the circulatory, gaseous exchange, digestive and excretory systems.</p> <p>Oxygen and carbon dioxide diffuse between blood in capillaries and air in alveoli. Water and dissolved food molecules are absorbed from the digestive system into blood in capillaries. Waste products including carbon dioxide and urea diffuse out of cells into the blood. Urea is filtered out of the blood by the kidneys into urine. Partially-permeable cell membranes regulate the movement of these substances; gases move across the membranes by diffusion, water by osmosis and some other substances by active transport.</p> <p>The heart, blood vessels, red blood cells and plasma are adapted to transport substances around the body.</p> <p>To sustain all the living cells inside humans and other multi-cellular organisms, exchange surfaces increase the surface area:volume ratio, and the circulatory system moves substances around the body to decrease the distance they have to diffuse to and from cells.</p>	1. describe some of the substances transported into and out of the human body in terms of the requirements of cells, including oxygen, carbon dioxide, water, dissolved food molecules and urea
	2. explain how the partially-permeable cell membranes of animal cells are related to diffusion, osmosis and active transport
	3. describe the human circulatory system, including its relationships with the gaseous exchange system, the digestive system and the excretory system
	4. explain how the structure of the heart is adapted to its function, including cardiac muscle, chambers and valves
	5. explain how the structures of arteries, veins and capillaries are adapted to their functions, including differences in the vessel walls and the presence of valves
	6. explain how red blood cells and plasma are adapted to their functions in the blood
	7. explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area:volume ratio
	8. calculate surface area:volume ratios M1c, M5c

Linked learning opportunities

Practical work:

- Dissect lamb's heart to observe atria, ventricles and valves.
- Investigate valves in an arm vein (tourniquet around bicep; when veins become prominent, gently try to push blood in each direction).

Practical work:

- Investigate the effect of surface area:volume ratio on diffusion of dye into agar cubes.

B5.2 How does the nervous system help us respond to changes?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>In order to survive, organisms need to detect and respond to changes in their external and internal environments. The highly adapted structures of the nervous system facilitate fast, short-lasting responses to stimuli.</p> <p>In a stimulated neuron, an electrical impulse passes along the axon. Most axons have a fatty sheath to increase impulse transmission speed. An impulse is transmitted from one neuron to another across a synapse by the release of transmitter substances, which diffuse across the gap and bind to receptors on the next neuron, stimulating it.</p> <p>Reflexes provide rapid, involuntary responses without involving a processing centre, and are essential to the survival of many organisms. In some circumstances the brain can modify a reflex response via a neuron to the motor neuron of the reflex arc (e.g. to stop us dropping a hot object).</p>	<p>1. explain how the components of the nervous system work together to enable it to function, including sensory receptors, sensory neurons, the CNS, motor neurons and effectors</p>
	<p>2. explain how the structures of nerve cells and synapses relate to their functions <i>① Learners are not expected to explain nerve impulse transmission in terms of membrane potentials</i></p>
	<p>3. a) explain how the structure of a reflex arc, including the relay neuron, is related to its function b) describe practical investigations into reflex actions</p>

Linked learning opportunities

B5.3 How do hormones control responses in the human body?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
The endocrine system of humans and other animals uses hormones, secreted by glands and transported by the blood, to enable the body to respond to external and internal stimuli. Hormones bind to receptors on effectors, stimulating a response. The endocrine system provides slower, longer-lasting responses than the nervous system. The production of hormones is regulated by negative feedback.	<ol style="list-style-type: none"> 1. describe the principles of hormonal coordination and control by the human endocrine system 2. explain the roles of thyroxine and adrenaline in the body, including thyroxine as an example of a negative feedback system.

Linked learning opportunities

B5.4 Why do we need to maintain a constant internal environment?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Cells, enzymes and life processes function only in certain conditions, and optimally when conditions are within a narrow range. The maintenance of a constant internal environment is homeostasis, and depends on receptors, nerves, hormones and (often antagonistic) effectors to counteract changes.	1. explain the importance of maintaining a constant internal environment in response to internal and external change
	2. in the context of maintaining a constant internal environment: a) extract and interpret data from graphs, charts and tables M2c b) translate information between numerical and graphical forms M4a

Linked learning opportunities

Specification links:

- The effects of temperature on enzyme activity (B3.1).

Practical work:

- Compare skin temperature and core body temperature under different conditions.
- Model the control of temperature by trying to keep a beaker of water at 40°C using just a Bunsen burner (single effector) compared to a Bunsen burner and ice (antagonistic effectors).

B5.5 What role do hormones play in human reproduction?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Hormones play a vital role in enabling sexual reproduction in humans: they regulate the menstrual cycle, including ovulation, in adult females. Without this process, sexual reproduction would not be possible.</p> <p>A number of hormones interact to control the menstrual cycle:</p> <ul style="list-style-type: none"> • FSH causes the ovaries to develop a follicle containing an egg, and produce oestrogen • oestrogen causes the uterus wall to thicken • LH causes the follicle to release the egg (ovulation) • the remains of the follicle secrete progesterone • progesterone prepares the lining of the uterus for implantation of a fertilised egg • oestrogen and progesterone stop the production of LH and FSH • as progesterone levels fall, the thickened uterus wall breaks down and is discharged (menstruation). <p>The menstrual cycle can be controlled artificially by the administration of hormones, often as an oral pill. The hormones prevent ovulation, so can be used as a contraceptive, but they do not decrease the risk of sexual transmission of communicable diseases (1aS4).</p> <p>Hormones can also be used to artificially manipulate the menstrual cycle as a treatment in certain cases of female infertility in which follicle development and ovulation do not occur successfully. The use of hormones to treat infertility is an example of an application of science that has made a significant positive difference to people's lives (1aS4).</p>	<ol style="list-style-type: none"> 1. describe the role of hormones in human reproduction, including the control of the menstrual cycle 2. explain the interactions of FSH, LH, oestrogen and progesterone in the control of the menstrual cycle 3. explain the use of hormones in contraception and evaluate hormonal and non-hormonal methods of contraception 4. explain the use of hormones in modern reproductive technologies to treat infertility

Linked learning opportunities

Specification links:

- Sexually transmitted disease (B2.1).

Ideas about Science:

- Risk in the context of sex and contraception (1aS4).

Ideas about Science:

- Infertility treatment as an application of science that makes a positive difference to lives (1aS4).

B5.6 What can happen when organs and control systems stop working?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Blood sugar level is controlled by insulin and glucagon acting antagonistically. Type 1 diabetes arises when the pancreas stops making insulin; blood sugar can be regulated using insulin injections. Type 2 diabetes develops when the body no longer responds to its own insulin or does not make enough insulin; blood sugar can be regulated using diet (high in complex carbohydrates), exercise and insulin injections.</p>	1. explain how insulin controls the blood sugar level in the body
	2. explain how glucagon and insulin work together to control the blood sugar level in the body
	3. compare type 1 and type 2 diabetes and explain how they can be treated

Linked learning opportunities

Chapter B6: Life on Earth – past, present and future

Overview

The modern explanation of evolution by natural selection is one of the central ideas in biology. The historical development of the explanation and its journey to widespread acceptance in the science community illustrate key *Ideas about Science*.

Learners explore ideas about evolution in Key Stages 2 and 3, so by Key Stage 4 they should be familiar with the concepts of variation (at phenotype level), adaptation, advantage, competition and natural selection. In Topic B6.1, learners begin to expand their understanding by linking variation to genetics, and the concept of evolution by natural selection is explored within the story of how the theory was developed, evaluated and modified by the scientific community. The topic considers the importance of

evidence as the basis for widespread scientific acceptance of the theory, and probes reasons why some people may still not accept it.

The effects that sexual and asexual reproduction have on evolution are considered in Topic B6.2, followed by a brief examination in Topic B6.3 of the impact that developments in scientific understanding have had on the way we classify the diversity of life on Earth today.

Finally, in Topic B6.4 learners examine the impacts of human activities on the Earth's biodiversity, the tremendous importance of protecting it, issues that affect decision making, and ways in which our understanding of science can help us to interact positively with ecosystems so that biodiversity and ecosystem resources are conserved for the future.

Learning about evolution and biodiversity before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- know that there are many different types of organisms living in many different environments, and that there are similarities and differences between all organisms
- recognise that living organisms can be grouped and classified in a variety of ways based on commonalities and differences
- be able to use classification keys
- recognise that living organisms have changed over time and that fossils provide information about organisms that lived millions of years ago
- appreciate that organisms live in habitats to which they are adapted
- recognise that organisms produce offspring of the same kind, but normally offspring vary and are not identical to their parents
- know that there is variation between individuals within a species, and that variation can be described as continuous or discontinuous
- understand that the variation means some organisms compete more successfully, resulting in natural selection
- appreciate that variation, adaptation, competition and natural selection result in the evolution of species
- understand that changes in the environment may leave organisms less well adapted to compete successfully and reproduce, which can lead to extinction
- be familiar with some of the reasons why it's important to protect and conserve biodiversity, and some ways of doing so.

Tiering

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

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

Learning about evolution and biodiversity at GCSE (9–1)

B6.1 How was the theory of evolution developed?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The modern theory of evolution by natural selection combines ideas about genes, variation, advantage and competition to explain how the inherited characteristics of a population can change over a number of generations. It includes the ideas that:</p> <p>Mutations in DNA create genetic variants, which may be inherited. Most genetic variants do not affect phenotype, but those that do may increase an organism's ability to survive in its environments and compete for resources (i.e. confer an advantage). Individuals with an advantage are more likely to reproduce; thus, by natural selection, the proportion of individuals possessing beneficial genetic variants increases in subsequent generations.</p> <p>A new species can arise if the organisms in a population evolve to be so different from their ancestors that they could no longer mate with them to produce fertile offspring. Speciation is more likely to occur when two populations of an organism are isolated.</p> <p>Charles Darwin noticed that the selective breeding of plants and animals had produced new varieties with many beneficial characteristics, quite different to their wild ancestors. Most of what we eat, and our ability to feed the growing human population, depends on selectively bred plants and animals. Darwin wondered whether a similar process of selection in nature could have created new species.</p>	1. state that there is usually extensive genetic variation within a population of a species
	2. recall that genetic variants arise from mutations, and that most have no effect on the phenotype, some influence phenotype and a very few determine phenotype
	3. explain how evolution occurs through natural selection of variants that give rise to phenotypes better suited to their environment
	4. explain the importance of competition in a community, with regard to natural selection
	5. describe evolution as a change in the inherited characteristics of a population over a number of generations through a process of natural selection which may result in the formation of new species
	6. explain the impact of the selective breeding of food plants and domesticated animals

Linked learning opportunities

B6.1 How was the theory of evolution developed?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The theory of evolution by natural selection was developed to explain observations made by Darwin, Wallace and other scientists, including:</p> <ul style="list-style-type: none"> the production of new varieties of plants and animals by selective breeding fossils with similarities and differences to living species the different characteristics shown by isolated populations of the same species living in different ecosystems. <p>The theory of evolution by natural selection illustrates how scientists continue to test a proposed explanation by making new observations and collecting new evidence, and how if the explanation is able to explain these it can become widely accepted by the scientific community (IaS3). For example, the spread of antibiotic resistance in bacteria can be explained by mutation, advantage and natural selection.</p>	<p>7. describe how fossils provide evidence for evolution</p> <p>8. describe modern examples of evidence for evolution including antibiotic resistance in bacteria</p>

Linked learning opportunities

Ideas about Science:

- The theory of evolution by natural selection as an example of how scientific explanations are developed (IaS3).

Ideas about Science:

- The theory of evolution by natural selection as a scientific explanation modified in light of new observations and ideas (IaS3).

B6.2 How does our understanding of biology help us classify the diversity of organisms on Earth?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The enormous diversity of organisms on Earth can be classified into groups on the basis of observed similarities and differences in their physical characteristics and, more recently, their DNA. We are more likely to classify species into the same group if there are lots of similarities in their genomes (i.e. if they have many genes, and genetic variants, in common). Genome analysis can also suggest whether different groups have a common ancestor, and how recently speciation occurred.</p>	<ol style="list-style-type: none"> 1. describe the impact of developments in biology on classification systems, including the use of DNA analysis to classify organisms

Linked learning opportunities

B6.3 Why is biodiversity threatened and how can we protect it?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The biodiversity of the Earth, or of a particular area, is the combination of the diversity of living organisms, the diversity of genes these organisms have, and the diversity of ecosystems.</p> <p>The biodiversity of many areas is being reduced by activities related to increasing human population size, industrialisation and globalisation. Such interactions can result in ecosystems being damaged or destroyed, populations dying out, and species becoming extinct when conditions change more quickly than they can adapt. Humans can interact with ecosystems positively by using ecosystem resources in a sustainable way (at the same rate as they can be replaced), and by protecting and conserving biodiversity.</p> <p>All organisms, including humans, depend on other organisms and the environment for their survival. Protecting and conserving biodiversity will help ensure we can continue to provide the human population with food, materials and medicines.</p> <p>Biodiversity can be protected at different levels, including protection of individual species, protection of ecosystems, and control of activities that contribute to global climate change. Decisions about protecting and conserving biodiversity are affected by ecological, economic, moral and political issues (1aS4).</p>	1. describe both positive and negative human interactions within ecosystems and explain their impact on biodiversity
	2. explain some of the benefits and challenges of maintaining local and global biodiversity
	3. extract and interpret information related to biodiversity from charts, graphs and tables M2c, M4a

Linked learning opportunities

Specification links:

- Greenhouse gases and global warming (P1.3, C1.1).

Ideas about Science:

- The impacts of science on biodiversity, including negative impacts and potential solutions (1aS4).
- Decision making in the context of the protection and conservation of biodiversity (1aS4).

Practical work:

- Measure living and non-living indicators to assess the effect of pollution on organisms.

Chapter C1: Air and water

Overview

The quality of our air and water is a major world concern. Chemists monitor our air and water, and work to minimise the impact of human activities on their quality.

In Topic C1.1, the context of changes in the Earth's atmosphere is used to explore the particle model and its limitations when explaining changes of state, and the principles of balancing equations for combustion reactions.

As a development of ideas about burning fuels, Topic C1.2 considers bonding in small

molecules and temperature changes in chemical reactions.

Topic C1.3 explores the evidence for climate change, asking why it might be occurring and how serious a threat it is. Learners consider environmental and health consequences of some air pollutants and climate change, and learn how scientists are helping to provide options for improving air quality and combatting global warming.

Finally, Topic C1.4 explores the need for increasing the amount of potable water worldwide, and techniques for obtaining potable water from ground, waste and salt water.

Learning about air and water before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be able to explain the properties of the different states of matter (solid, liquid and gas) in terms of the particle model, including gas pressure
- appreciate the differences between atoms, elements and compounds
- be familiar with the use of chemical symbols and formulae for elements and compounds
- know about conservation of mass, changes of state and chemical reactions
- be able to explain changes of state in terms of the particle model
- know that there are energy changes on changes of state (qualitative)
- know about exothermic and endothermic chemical reactions (qualitative)
- understand the carbon cycle
- know the composition of the Earth's atmosphere today
- know about the production of carbon dioxide by human activity and its impact on climate.

Tiering

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

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

Learning about air and water at GCSE (9–1)

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

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

Linked learning opportunities

Practical work:

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

Ideas about Science:

- Use the particle model to explain state changes (IaS3).

Ideas about Science:

- Distinguish data from explanatory ideas in accounts of how the atmosphere was formed (IaS3).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Our modern lifestyle has created a high demand for energy. Combustion of fossil fuels for transport and energy generation leads to emissions of pollutants.</p> <p>Carbon monoxide, sulfur dioxide, nitrogen oxides and particulates directly harm human health. Some pollutants cause indirect problems to humans and the environment by the formation of acid rain and smog. Scientists monitor the concentration of these pollutants in the atmosphere and strive to develop approaches to maintaining air quality (IaS4).</p> <p>The combustion reactions of fuels and the formation of pollutants can be represented using word and symbol equations. The formulae involved in these reactions can be represented by models, diagrams or written formulae. The equations should be balanced.</p> <p>When a substance chemically combines with oxygen it is an example of oxidation. Combustion reactions are therefore oxidation.</p> <p>Some gases involved in combustion reactions can be identified by their chemical reactions.</p>	7. describe the major sources of carbon monoxide and particulates (incomplete combustion), sulfur dioxide (combustion of sulfur impurities in fuels), oxides of nitrogen (oxidation of nitrogen at high temperatures and further oxidation in the air)
	8. explain the problems caused by increased amounts of these substances and describe approaches to decreasing the emissions of these substances into the atmosphere including the use of catalytic converters, low sulfur petrol and gas scrubbers to decrease emissions
	9. use chemical symbols to write the formulae of elements and simple covalent compounds
	10. use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations
	11. use arithmetic computations and ratios when balancing equations M1a, M1c
	12. describe tests to identify oxygen, hydrogen and carbon dioxide PAGC2
	13. explain oxidation in terms of gain of oxygen

Linked learning opportunities

Ideas about Science:

- Unintended impacts of burning fossil fuels on air quality (IaS4).
- Catalytic converters, low sulfur petrol and gas scrubbers as positive applications of science (IaS4).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>When a fuel is burned in oxygen the surroundings are warmed; this is an example of an exothermic reaction. There are also chemical reactions that cool their surroundings; these are endothermic reactions.</p> <p>Energy has to be supplied before a fuel burns. For all reactions, there is a certain minimum energy needed to break bonds so that the reaction can begin. This is the activation energy. The activation energy, and the amount of energy associated with the reactants and products, can be represented using a reaction profile.</p> <p>Atoms are rearranged in chemical reactions. This means that bonds between the atoms must be broken and then reformed. Breaking bonds requires energy (the activation energy) whilst making bonds gives out energy.</p> <p>Energy changes in a reaction can be calculated if we know the bond energies involved in the reaction.</p>	1. distinguish between endothermic and exothermic reactions on the basis of the temperature change of the surroundings
	2. draw and label a reaction profile for an exothermic and an endothermic reaction, identifying activation energy
	3. explain activation energy as the energy needed for a reaction to occur
	4. interpret charts and graphs when dealing with reaction profiles
	5. calculate energy changes in a chemical reaction by considering bond breaking and bond making energies M1a, M1c, M1d
	6. carry out arithmetic computations when calculating energy changes M1a, M1c, M1d

Linked learning opportunities

Practical work:

- Investigate different chemical reactions to find out if they are exothermic or endothermic.

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Some electromagnetic radiation from the Sun passes through the atmosphere and is absorbed by the Earth warming it. The warm Earth emits infrared radiation which some gases, including carbon dioxide and methane, absorb and re-emit in all directions; this keeps the Earth warmer than it would otherwise be and is called the greenhouse effect. Without the greenhouse effect the Earth would be too cold to support life.</p> <p>The proportion of greenhouse gases in the Earth's atmosphere has increased over the last 200 years as a result of human activities. There are correlations between changes in the composition of the atmosphere, consumption of fossil fuels and global temperatures over time. Although there are uncertainties in the data, most scientists now accept that recent climate change can be explained by increased greenhouse gas emissions.</p> <p>Patterns in the data have been used to propose models to predict future climate changes. As more data is collected, the uncertainties in the data decrease, and our confidence in models and their predictions increases (1a3).</p> <p>Scientists aim to reduce emissions of greenhouse gases, for example by reducing fossil fuel use and removing gases from the atmosphere by carbon capture and reforestation. These actions need to be supported by public regulation. Even so, it is difficult to mitigate the effect of emissions due to the very large scales involved. Each new measure may have unforeseen impacts on the environment, making it difficult to make reasoned judgments about benefits and risks (1a4).</p>	1. describe the greenhouse effect in terms of the interaction of radiation with matter
	2. evaluate the evidence for additional anthropogenic causes of climate change, including the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels, and describe the uncertainties in the evidence base
	3. describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate including where crops can be grown, extreme weather patterns, melting of polar ice and flooding of low land
	4. describe how the effects of increased levels of carbon dioxide and methane may be mitigated, including consideration of scale, risk and environmental implications
	5. extract and interpret information from charts, graphs and tables M2c, M4a
	6. use orders of magnitude to evaluate the significance of data M2h

Linked learning opportunities

Specification links:

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

Practical work:

- Investigate climate change models – both physical models and computer models.

Ideas about Science:

- Use ideas about correlation and cause, about models and the way science explanations are developed when discussing climate change (1a3).
- Risks, costs and benefits of fuel use and its sustainability and effects on climate (1a4).
- Public regulation of targets for emissions and reasons why different decisions on issues related to climate change might be made in view of differences in personal, social, or economic context (1a4).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The increase in global population means there is a greater need for potable water. Obtaining potable water depends on the availability of waste, ground or salt water and treatment methods.</p> <p>Chlorine is used to kill microorganisms in water. The benefits of adding chlorine to water to stop the spread of waterborne diseases outweigh risks of toxicity. In some countries the chlorination of water is subject to public regulation, but other parts of the world are still without chlorinated water and this leads to a higher risk of disease (1aS4).</p>	<p>1. describe the principal methods for increasing the availability of potable water in terms of separation techniques used, including the ease of treating waste, ground and salt water including filtration and membrane filtration; aeration, use of bacteria; chlorination and distillation (for salt water)</p>
	<p>2. describe a test to identify chlorine (using blue litmus paper) <i>PAGC1</i></p>

Linked learning opportunities

Ideas about Science:

- Technologies to increase the availability of potable water can make a positive difference to people's lives (1aS4).
- Access to treated water raises issues about risk, cost and benefit and providing treated water for all raises ethical issues (1aS4).

Practical work:

- Identify unknown gases.

Chapter C2: Chemical patterns

Overview

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

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

The first two topics of the chapter give opportunities for learners to develop understanding of ideas about science; how scientific knowledge develops, the

relationship between evidence and explanations, and how the scientific community responds to new ideas. The later topics present some of the most important models which underpin an understanding of atoms, chemical behaviour and patterns and how reactions are represented in chemical equations.

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

Learning about chemical patterns before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

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

Tiering

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

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

Learning about chemical patterns at GCSE (9–1)

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The modern model of the atom developed over time. Stages in the development of the model included ideas by the ancient Greeks (4 element ideas), Dalton (first particle model), Thomson ('plum pudding' model), Rutherford (idea of atomic nucleus) and Bohr (shells of electrons). Models were rejected, modified and extended as new evidence became available. The development of the atomic model involved scientists suggesting explanations, making and checking predictions based on their explanations, and building on each other's work (1aS3).</p> <p>The Periodic Table can be used to find the atomic number and relative atomic mass of an atom of an element, and then work out the numbers of protons, neutrons and electrons. The number of electrons in each shell can be represented by simple conventions such as dots in circles or as a set of numbers (for example, sodium as 2.8.1).</p> <p>Atoms are small – about 10^{-10} m across, and the nucleus is at the centre, about a hundred-thousandth of the diameter of the atom. Molecules are larger, containing from two to hundreds of atoms. Objects that can be seen with the naked eye contain millions of atoms.</p>	1. describe how and why the atomic model has changed over time to include the main ideas of Dalton, Thomson, Rutherford and Bohr
	2. describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with most of the mass in the nucleus
	3. recall relative charges and approximate relative masses of protons, neutrons and electrons
	4. estimate the size and scale of atoms relative to other particles M1d
	5. recall the typical size (order of magnitude) of atoms and small molecules
	6. relate size and scale of atoms to objects in the physical world M1d
	7. calculate numbers of protons, neutrons and electrons in atoms, given atomic number and mass number of isotopes or by extracting data from the Periodic Table M1a

Linked learning opportunities

Specification links:

- Atoms and radiation (P5.1).

Ideas about Science:

- Understanding how scientific explanations and models develop in the context of changing ideas about the atomic model (1aS3).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Elements in the modern Periodic Table are arranged in periods and groups, based on their atomic numbers. Elements in the same group have the same number of electrons in their outer shells. The number of electron shells increases down a group but stays the same across a period.	1. explain how the position of an element in the Periodic Table is related to the arrangement of electrons in its atoms and hence to its atomic number
Mendeleev proposed the first arrangement of elements in the Periodic Table. Although he did not know about atomic structure, he reversed the order of some elements with respect to their masses, left gaps for undiscovered elements and predicted their properties. His ideas were accepted because when certain elements were discovered they fitted his gaps and the development of a model for atomic structure supported his arrangement. The later determination of the number of protons in atoms provided an explanation for the order he proposed (1aS3).	2. describe how Mendeleev organised the elements based on their properties and relative atomic masses
The Periodic Table shows repeating patterns in the properties of the elements. Metals and non-metals can be identified by their position in the Periodic Table and by comparing their properties (physical properties including electrical conductivity).	3. describe how discovery of new elements and the ordering elements by atomic number supports Mendeleev's decisions to leave gaps and reorder some elements
Properties of elements within a group show trends. The reactivity of Group 1 metals elements increases down the group, shown by their reactivity with moist air, water and chlorine.	4. describe metals and non-metals and explain the differences between them on the basis of their characteristic physical and chemical properties, including melting point, boiling point, state and appearance, density, formulae of compounds, relative reactivity and electrical conductivity
The Group 7 halogens are non-metals and become less reactive down the group. This is shown in reactions such as their displacement reactions with compounds of other halogens in the group.	5. recall the simple properties of Group 1 elements including their reaction with moist air, water, and chlorine
	6. recall the simple properties of Group 7 elements including their states and colours at room temperature and pressure, their colours as gases, their reactions with Group 1 elements and their displacement reactions with other metal halides
	7. predict possible reactions and probable reactivity of elements from their positions in the Periodic Table
	8. describe experiments to identify the reactivity pattern of Group 7 elements including displacement reactions
	9. describe experiments to identify the reactivity pattern of Group 1 elements

Linked learning opportunities

Practical work:

- Reactions of Group 1 (demonstration) and Group 7 (for example displacement).

Ideas about Science:

- Understanding how scientific explanations and models develop, in the context of the Periodic Table (1aS3).

Ideas about Science:

- Making and testing predictions about trends and patterns in the Periodic Table (1aS1).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Group 0 contains elements with a full outer shell of electrons. This arrangement is linked to their inert, unreactive properties. They exist as single atoms and hence are gases with low melting and boiling points.	1. recall the simple properties of Group 0 including their low melting and boiling points, their state at room temperature and pressure and their lack of chemical reactivity
Group 1 elements combine with Group 7 elements by ionic bonding. This involves a transfer of electrons leading to charged ions. Atoms and ions can be represented using dot and cross diagrams as simple models (1a33). Metals, such as Group 1 elements, lose electrons from the outer shell of their atoms to form ions with complete outer shells and with a positive charge. Non-metals, such as Group 7 elements, form ions with a negative charge by gaining electrons to fill their outer shell. The number of electrons lost or gained determines the charge on the ion.	2. explain how observed simple properties of Groups 1, 7 and 0 depend on the outer shell of electrons of the atoms and predict properties from given trends down the groups
The properties of ionic compounds such as group 1 halides can be explained in terms of the ionic bonding. Positive ions and negative ions are strongly attracted together and form giant lattices. Ionic compounds have high melting points in comparison to many other substances due to the strong attraction between ions which means a large amount of energy is needed to break the attraction between the ions. They dissolve in water because their charges allow them to interact with water molecules. They conduct electricity when molten or in solution because the charged ions can move, but not when solid because the ions are held in fixed positions.	3. explain how the reactions of elements are related to the arrangement of electrons in their atoms and hence to their atomic number
	4. explain how the atomic structure of metals and non-metals relates to their position in the Periodic Table
	5. describe the nature and arrangement of chemical bonds in ionic compounds
	6. explain ionic bonding in terms of electrostatic forces and transfer of electrons
	7. calculate numbers of protons, neutrons and electrons in atoms and ions, given atomic number and mass number or by using the Periodic Table M1a
	8. construct dot and cross diagrams for simple ionic substances
	9. explain how the bulk properties of ionic materials are related to the type of bonds they contain

Linked learning opportunities

Practical work:

- Test the properties of ionic compounds.

Ideas about Science:

- Dot and cross diagrams as models of atoms and ions, and the limitations of these models (1a33).
- 2-D and 3-D representations as simple models of the arrangement of ions, and the limitations of these models (1a33).

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

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

Linked learning opportunities

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

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

Linked learning opportunities

Chapter C3: Chemicals of the natural environment

Overview

Our way of life depends on a wide range of products made from natural resources. The Earth's crust provides us with metal ores and crude oil and our use of these impacts on the natural environment.

Chemistry is fundamental to an understanding of the scale and significance of this human activity.

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

technologies enable us to extract metals from poor quality ores.

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

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

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

From study at Key Stages 1 to 3 learners should:

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

Tiering

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

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

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

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Chemists use a model of metal structure to explain the properties of metals (1aS3). In the model, metal atoms are arranged closely together in a giant structure, held together by attraction between the positively charged atoms and a ‘sea’ of negatively charged electrons. Metals are malleable and ductile because the ions can slide over each other but still be held together by the electrons; they conduct electricity and heat because their electrons are free to move; and they have high boiling points and melting points due to the strong electrostatic attraction between metal ions and the electrons. These properties of metals make them useful.	1. describe the nature and arrangement of chemical bonds in metals
	2. explain how the bulk properties of metals are related to the type of bonds they contain

Linked learning opportunities

Ideas about Science:

- Use the model of metal structure to explain properties of metals (1aS3).

C3.2 How are metals with different reactivities extracted?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Metals can be placed in an order of reactivity by looking at their reactions with water, dilute acid and compounds of other metals. The relative reactivity of metals enables us to make predictions about which metals react fastest or which metal will displace another.	1. deduce an order of reactivity of metals based on experimental results including reactions with water, dilute acid and displacement reactions with other metals
When metals react they form ionic compounds. The metal atoms lose one or more electrons to become positive ions. The more easily this happens the more reactive the metal.	2. explain how the reactivity of metals with water or dilute acids is related to the tendency of the metal to form its positive ion to include potassium, sodium, calcium, aluminium, magnesium, zinc, iron, lead, [hydrogen], copper, silver
These reactions can be represented by word and symbol equations including state symbols. Ionic equations show only the ions that change in the reaction and show the gain or loss of electrons. They are useful for representing displacement reactions because they show what happens to the metal ions during the reaction.	3. use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations and ionic equations
The way a metal is extracted depends on its reactivity. Some metals are extracted by reacting the metal compound in their ores with carbon.	4. explain, using the position of carbon in the reactivity series, the principles of industrial processes used to extract metals, including the extraction of zinc
Carbon is a non-metal but can be placed in the reactivity series of the metals between aluminium and zinc.	5. explain why electrolysis is used to extract some metals from their ores
Metals below carbon in the reactivity series are extracted from their ores by displacement by carbon. The metal in the ore is reduced and carbon is oxidised.	6. evaluate alternative biological methods of metal extraction (bacterial and phytoextraction)
Highly reactive metals above carbon in the reactivity series are extracted by electrolysis.	
Scientists are developing methods of extracting the more unreactive metals from their ores using bacteria or plants. These methods can extract metals from waste material, reduce the need to extract 'new' ores, reduce energy costs, and reduce the amount of toxic metals in landfill. However, these methods do not produce large quantities of metals quickly (1aS4).	

Linked learning opportunities

Practical work:

- Investigate the reactivity of different metals with water and dilute acid.
- Investigate the reactivity of Zn, Fe and Cu by heating each metal with oxides of each of the other two metals.

Specification links:

- Introduces oxidation and reduction (C1.1).

Ideas about Science:

- Impacts of metal extraction on the environment, the measures scientists are taking to mitigate them, and the risks, costs and benefits of different courses of action (1aS4).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Electrolysis is used to extract reactive metals from their ores. Electrolysis is the decomposition of an electrolyte by an electric current. Electrolytes include molten and dissolved ionic compounds. In both cases the ions are free to move.	1. describe electrolysis in terms of the ions present and reactions at the electrodes
During electrolysis non-metal ions lose electrons to the anode to become neutral atoms. Metal (or hydrogen) ions gain electrons at the cathode to become neutral atoms. The addition or removal of electrons can be used to identify which species are reduced and which are oxidised. These changes can be summarised using half equations.	2. predict the products of electrolysis of binary ionic compounds in the molten state
Electrolysis is used to extract reactive metals from their molten compounds. During the electrolysis of aluminium, aluminium oxide is heated to a very high temperature. Positively charged aluminium ions gain electrons from the cathode to form atoms. Oxygen ions lose electrons at the anode and form oxygen molecules which react with carbon electrodes to form carbon dioxide. The process uses a large amount of energy for both the high temperature and the electricity involved in electrolysis.	3. recall that metals (or hydrogen) are formed at the cathode and non-metals are formed at the anode in electrolysis using inert electrodes
Some extraction methods, such as the recovery of metals from waste heaps, give a dilute aqueous solution of metals ions.	4. use the names and symbols of common elements and compounds and the principle of conservation of mass to write half equations
When an electric current is passed through an aqueous solution the water is electrolysed as well as the ionic compound. Less reactive metals such as silver or copper form on the negative electrode. If the solution contains ions of more reactive metals, hydrogen gas forms from the hydrogen ions from the water. Similarly, oxygen usually forms at the positive electrode from hydroxide ions from the water. A concentrated solution of chloride ions forms chlorine at the positive electrode.	5. explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced
	6. explain how electrolysis is used to extract some metals from their ores including the extraction of aluminium
	7. describe competing reactions in the electrolysis of aqueous solutions of ionic compounds in terms of the different species present including the formation of oxygen, chlorine and the discharge of metals or hydrogen linked to their relative reactivity
	8. describe the technique of electrolysis of an aqueous solution of a salt <i>PAGC1</i>

Linked learning opportunities

Practical work:

- Investigate what type of substances are electrolytes.

Practical work:

- Investigate the effects of concentration of aqueous solution, current, voltage on the electrolysis of sodium chloride.

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Crude oil is mixture of hydrocarbons. It is used as a source of fuels and as a feedstock for making chemicals (including polymers) for a very wide range of consumer products. Almost all of the consumer products we use involve the use of crude oil in their manufacture or transport.</p> <p>Crude oil is finite. If we continue to burn it at our present rate it will run out in the near future. Crude oil makes a significant positive difference to our lives, but our current use of crude oil is not sustainable. Decision about the use of crude oil must balance short-term benefits with the need to conserve this resource for future generations (1aS4).</p> <p>Crude oil is a mixture. It needs to be separated into groups of molecules of similar size called fractions. This is done by fractional distillation. Fractional distillation depends on the different boiling points of the hydrocarbons, which in turn is related to the size of the molecules and the intermolecular forces between them.</p> <p>The fractions are mixtures, mainly of alkanes, with a narrow range of boiling points. The first four alkanes show typical properties of a homologous series: each subsequent member increases in size by CH_2, they have a general formula and show trends in their physical and chemical properties.</p> <p>The molecular formula of an alkane shows the number of atoms present in each molecule. These formulae can be simplified to show the simplest ratio of carbon to hydrogen atoms. This type of formula is an empirical formula.</p>	1. recall that crude oil is a main source of hydrocarbons and is a feedstock for the petrochemical industry
	2. explain how modern life is crucially dependent upon hydrocarbons and recognise that crude oil is a finite resource
	3. describe and explain the separation of crude oil by fractional distillation <i>PAGC2</i>
	4. describe the fractions of crude oil as largely a mixture of compounds of formula $\text{C}_n\text{H}_{2n+2}$ which are members of the alkane homologous series
	5. use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur
	6. deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa
	7. use arithmetic computation and ratio when determining empirical formulae <i>M1c</i>
	8. describe the arrangement of chemical bonds in simple molecules
	9. explain covalent bonding in terms of the sharing of electrons

Linked learning opportunities

Ideas about Science:

- Decision making in the context of the use of crude oil for fuels and as a feedstock (1aS4).

Ideas about Science:

- The use and limitations of models to represent bonding in simple molecules (1aS3).

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

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

Linked learning opportunities

Ideas about Science:

- Cracking as a positive application of science, to reduce extraction of crude oil and so conserves oil reserves (IaS4).

Chapter C4: Material choices

Overview

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

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

Topic C4.2 extends the study of properties to looking at bonding and structure in order to explain why a particular material behaves as it does. Learners learn about the bonding in metals, polymers and giant covalent structures and link the bonding and structure to the properties of the materials. They consider the usefulness of diagrams and models of bonding and structure to chemists who need to investigate and predict properties of materials so that they can make judgements about their usefulness or model likely changes in their properties if their structures are modified. A range of materials are studied, including new materials such as fullerenes and graphene.

Topic C4.3 looks specifically at the nature and uses of nanoparticles.

Topic C4.4 considers the life cycle of materials. They learn how the impact of our manufacture, use and disposal of consumer products is assessed using life cycle assessments.

Learning about material choices before GCSE (9–1)

From study at Key Stages 1 to 3 Learners should:

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

2

Tiering

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

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

Learning about material choices at GCSE (9–1)

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Our society uses a large range of materials and products developed by chemists. Chemists assess materials by measuring their physical properties, and use data to compare different materials and to match materials to the specification of a useful product (1aS4).	1. compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals including melting point, softening temperature (for polymers), electrical conductivity, strength (in tension or compression), stiffness, flexibility, brittleness, hardness, density, ease of reshaping
Composites have a very broad range of uses as they allow the properties of several materials to be combined. Composites may have materials combined on a bulk scale (for example, using steel to reinforce concrete) or have nanoparticles incorporated in a material or embedded in a matrix.	2. explain how the properties of materials are related to their uses and select appropriate materials given details of the usage required

Linked learning opportunities**Practical work:**

- Practical investigation of a range of materials leading to classification into categories.

Ideas about Science:

- The range of materials developed by chemists enhances the quality of life (1aS4).
- Use and limitations of a model to represent structures (1aS3).

C4.2 How do bonding and structure affect properties of materials?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Different materials can be made from the same atoms but have different properties if they have different types of bonding or structures. Chemists use ideas about bonding and structure when they predict the properties of a new material or when they are researching how an existing material can be adapted to enhance its properties.	1. explain how the bulk properties of materials (including strength, melting point, electrical and thermal conductivity, brittleness, flexibility, hardness and ease of reshaping) are related to the different types of bonds they contain, their bond strengths in relation to intermolecular forces and the ways in which their bonds are arranged, recognising that the atoms themselves do not have these properties
Carbon is an unusual element because it can form chains and rings with itself. This leads to a vast array of natural and synthetic compounds of carbon with a very wide range of properties and uses. ‘Families’ of carbon compounds are homologous series.	2. recall that carbon can form four covalent bonds
Polymer molecules have the same strong covalent bonding as simple molecular compounds, but there are more intermolecular forces between the molecules due to their length. The strength of the intermolecular forces affects the properties of the solid.	3. explain that the vast array of natural and synthetic organic compounds occurs due to the ability of carbon to form families of similar compounds, chains and rings
Giant covalent structures contain many atoms bonded together in a 3 dimensional arrangement by covalent bonds. The ability of carbon to bond with itself gives rise to a variety of materials which have different giant covalent structures of carbon atoms. These are allotropes, and include diamond and graphite. These materials have different properties which arise from their different structures.	4. describe the nature and arrangement of chemical bonds in polymers with reference to their properties including strength, flexibility or stiffness, hardness and melting point of the solid
	5. describe the nature and arrangement of chemical bonds in giant covalent structures
	6. explain the properties of diamond and graphite in terms of their structures and bonding including melting point, hardness and (for graphite) conductivity and lubricating action
	7. represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures e.g. allotropes of carbon M5b
	8. describe and compare the nature and arrangement of chemical bonds in ionic compounds, simple molecules, giant covalent structures, polymers and metals

Linked learning opportunities

Specification links

- Ionic bonding and structure (C2.3).
- Simple molecules (C2.3) and metallic bonding (C3.1).
- Covalent bonds and intermolecular forces (C3.4).

Practical work:

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

Ideas about Science:

- Identify patterns in data related to polymers and allotropes of carbon (1aS2).
- Use and limitations of a model to represent the structures of a range of materials (1aS3).

C4.3 Why are nanoparticles so useful?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Nanoparticles have a similar scale to individual molecules. Their extremely small size means they can penetrate into biological tissues and can be incorporated into other materials to modify their properties. Nanoparticles have a very high surface area to volume ratio. This makes them excellent catalysts.</p> <p>Fullerenes form nanotubes and balls. The ball structure enables them to carry small molecules, for example carrying drugs into the body. The small size of fullerene nanotubes enables them to be used as molecular sieves and to be incorporated into other materials (for example to increase strength of sports equipment). Graphene sheets have specialised uses because they are only a single atom thick but are very strong with high electrical and thermal conductivity.</p> <p>Developing technologies based on fullerenes and graphene required leaps of imagination from creative thinkers (IaS3).</p> <p>There are concerns about the safety of some nanoparticles because not much is known about their effects on the human body. Judgements about a particular use for nanoparticles depend on balancing the perceived benefit and risk (IaS4).</p>	1. compare 'nano' dimensions to typical dimensions of atoms and molecules
	2. describe the surface area to volume relationship for different-sized particles and describe how this affects properties
	3. describe how the properties of nanoparticulate materials are related to their uses including properties which arise from their size, surface area and arrangement of atoms in tubes or rings
	4. explain the properties fullerenes and graphene in terms of their structures
	5. explain the possible risks associated with some nanoparticulate materials, including: <ol style="list-style-type: none"> possible effects on health due to their size and surface area reasons that there is more data about uses of nanoparticles than about possible health effects the relative risks and benefits of using nanoparticles for different purposes

Linked learning opportunities

Ideas about Science:

- Discuss the potential benefits and risks of developments in nanotechnology (IaS4).
- Development of nanoparticles and graphene relied on imaginative thinking (IaS3).

C4.3 Why are nanoparticles so useful?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	<p>6. estimate size and scale of atoms and nanoparticles including the ideas that:</p> <ul style="list-style-type: none"> a) nanotechnology is the use and control of structures that are very small (1 to 100 nanometres in size) b) data expressed in nanometres is used to compare the sizes of nanoparticles, atoms and molecules <p>M1d</p>
	<p>7. interpret, order and calculate with numbers written in standard form when dealing with nanoparticles</p> <p>M1b</p>
	<p>8. use ratios when considering relative sizes and surface area to volume comparisons</p> <p>M1c</p>
	<p>9. calculate surface areas and volumes of cubes</p> <p>M5c</p>

Linked learning opportunities

C4.4 What happens to products at the end of their useful life?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Iron is the most widely used metal in the world. The useful life of products made from iron is limited because iron corrodes. This involves an oxidation reaction with oxygen from the air.</p> <p>Life cycle assessments (LCAs) are used to consider the overall impact of our making, using and disposing of a product. LCAs involve considering the use of resources and the impact on the environment of all stages of making materials for a product from raw materials, making the finished product, the use of the product, transport and the method used for its disposal at the end of its useful life.</p> <p>It is difficult to make secure judgments when writing LCAs because there is not always enough data and people do not always follow recommended disposal advice (IaS4).</p> <p>Some products can be recycled at the end of their useful life. In recycling, the products are broken down into the materials used to make them; these materials are then used to make something else. Reusing products uses less energy than recycling them. Reusing and recycling both affects the LCA.</p> <p>Recycling conserves resources such as crude oil and metal ores, but will not be sufficient to meet future demand for these resources unless habits change.</p> <p>The viability of a recycling process depends on a number of factors: the finite nature of some deposits of raw materials (such as metal ores and crude oil), availability of the material to be recycled, economic and practical considerations of collection and sorting, removal of impurities, energy use in transport and processing, scale of demand for new product, environmental impact of the process.</p> <p>Products made from recycled materials do not always have a lower environmental impact than those made from new resources (IaS4).</p>	1. explain reduction and oxidation in terms of loss or gain of oxygen, identifying which species are oxidised and which are reduced
	2. explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced
	3. describe the basic principles in carrying out a life-cycle assessment of a material or product including: <ol style="list-style-type: none"> the use of water, energy and the environmental impact of each stage in a life cycle, including its manufacture, transport and disposal incineration, landfill and electricity generation schemes biodegradable and non-biodegradable materials
	4. interpret data from a life-cycle assessment of a material or product
	5. describe the process where PET drinks bottles are reused and recycled for different uses, and explain why this is viable
	6. evaluate factors that affect decisions on recycling with reference to products made from crude oil and metal ores

Linked learning opportunities

Practical work:

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

Ideas about Science:

- Use the example of applying scientific solutions to the problem of corrosion of metals to explain the idea of improving sustainability (IaS4).
- Use life-cycle assessments to compare the sustainability of products and processes (IaS4).

Chapter C5: Chemical analysis

Overview

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

The chapter begins in Topic C5.1 by considering why it is necessary to purify chemicals and how the

components of mixtures are separated. Methods of testing for purity and separating mixtures are studied, including chromatography and a range of practical separation techniques.

Topic C5.2 introduces quantitative work. The mole is used as a measure of amounts of substance and learners process data from formulae and equations to work out quantities of reactants and products.

Topic C5.3 develops quantitative work further to show how the concentrations of solutions are determined. This has applications for the testing and quality control of manufactured chemical products and also allows the analysis of unknown chemicals for a range of purposes (for example in forensics, in drug production, mineral exploration and environmental monitoring). Learners make a standard solution and analyse the concentration of unknown solutions using titrations.

Learning about chemical analysis before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

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

Tiering

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

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

Learning about chemical analysis at GCSE (9–1)

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Many useful products contain mixtures. It is important that consumer products such as drugs or personal care products do not include impurities. Mixtures in many consumer products contain pure substances mixed together in definite proportions called formulations.</p> <p>Pure substances contain a single element or compound. Chemists test substances made in the laboratory and in manufacturing processes to check that they are pure. One way of assessing the purity of a substance is by testing its melting point; pure substances have sharp melting points and can be identified by matching melting point data to reference values.</p> <p>Chromatography is used to see if a substance is pure or to identify the substances in a mixture. Components of a mixture are identified by the relative distance travelled compared to the distance travelled by the solvent. R_f values can be calculated and used to identify unknown components by comparison to reference samples. Some substances are insoluble in water, so other solvents are used. Chromatography can be used on colourless substances but locating agents are needed to show the spots.</p>	1. explain that many useful materials are formulations of mixtures
	2. explain what is meant by the purity of a substance, distinguishing between the scientific and everyday use of the term 'pure'
	3. use melting point data to distinguish pure from impure substances
	4. recall that chromatography involves a stationary and a mobile phase and that separation depends on the distribution between the phases
	5. interpret chromatograms, including calculating R _f values M3c
	6. suggest chromatographic methods for distinguishing pure from impure substances PAGC3 Including the use of: a) paper chromatography b) aqueous and non-aqueous solvents c) locating agents

Linked learning opportunities

Specification links:

- Particle model and changes of state (C1.1).
- Fractional distillation of crude oil on an industrial scale (C3.4).

Ideas about Science

- Use the particle model to explain the idea of a pure substance.

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Preparation of chemicals often produces impure products or a mixture of products. Separation processes in both the laboratory and in industry enable useful products to be separated from by-products and waste products. The components of mixtures are separated using processes that exploit the different properties of the components, (for example state, boiling points, or solubility in different solvents).</p> <p>Separation processes are rarely completely successful and mixtures often need to go through several stages or through repeated processes to reach an acceptable purity.</p>	<p>7. describe, explain and exemplify the processes of filtration, crystallisation, simple distillation, and fractional distillation <i>PAGC2, PAGC4</i></p>
	<p>8. suggest suitable purification techniques given information about the substances involved <i>PAGC2, PAGC4</i></p>

Linked learning opportunities

C5.2 How are the amounts of substances in reactions calculated?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
During reactions, atoms are rearranged but the total mass does not change. Reactions in open systems often appear to have a change in mass because substances are gained or lost, usually to the air.	1. recall and use the law of conservation of mass
Chemists use relative masses to measure the amounts of chemicals. Relative atomic masses for atoms of elements can be obtained from the Periodic Table.	2. explain any observed changes in mass in non-enclosed systems during a chemical reaction and explain them using the particle model
The relative formula mass of a compound can be calculated using its formula and the relative atomic masses of the atoms it contains.	3. calculate relative formula masses of species separately and in a balanced chemical equation
Counting atoms or formula units of compounds involves very large numbers, so chemists use a mole as a unit of counting. One mole contains 6.0×10^{23} atoms or formula units; this is the Avogadro constant. It is more convenient to count atoms as 'numbers of moles'.	4. recall and use the definitions of the Avogadro constant (in standard form) and of the mole
In recognition of IUPAC's review, we will accept both the classical (carbon-12 based) and revised (Avogadro constant based) definitions of the mole in examinations from June 2018 onwards (see https://iupac.org/new-definition-mole-arrived/)	5. explain how the mass of a given substance is related to the amount of that substance in moles and vice versa and use the relationship: $\text{number of moles} = \frac{\text{mass of substance (g)}}{\text{relative formula mass (g)}}$ M2a, M3c
The number of moles of a substance can be worked out from its mass, this is useful to chemists because they can use the equations for reactions to work out the amounts of reactants to use in the correct proportions to make a particular product, or to work out which reactant is used up when a reaction stops.	6. deduce the stoichiometry of an equation from the masses of reactants and products and explain the effect of a limiting quantity of a reactant
	7. use a balanced equation to calculate masses of reactants or products M1a, M1c

Linked learning opportunities

Specification links

- The particle model (C1.1).
- Maximising industrial yields (C6.3).

Practical work:

- Comparison of theoretical and actual yield from the preparation of an organic compound (introduced in C3) or a salt (introduced in C5).

Practical work:

- Making and testing predictions. Carrying out investigations. Analysing and evaluating data. Using measuring apparatus. Safe handling of chemicals.

C5.2 How are the amounts of substances in reactions calculated?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
The equation for a reaction can also be used to work out how much product can be made starting from a known amount of reactants. This is useful to determine the amounts of reacting chemicals to be used in industrial processes so that processes can run as efficiently as possible.	8. use arithmetic computation, ratio, percentage and multistep calculations throughout quantitative chemistry M1a, M1c, M1d
	9. carry out calculations with numbers written in standard form when using the Avogadro constant M1b
	10. change the subject of a mathematical equation M3c

Linked learning opportunities

Ideas about Science:

- Using data to make quantitative predictions about yields and comparing them to actual yields (IaS1, IaS2).

C5.3 How are the amounts of chemicals in solution measured?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Quantitative analysis is used by chemists to make measurements and calculations to show the amounts of each component in a sample.</p> <p>Concentrations sometimes use the units g/dm³ but more often are expressed using moles, with the units mol/dm³. Expressing concentration using moles is more useful because it links more easily to the reacting ratios in the equation.</p> <p>The concentration of acids and alkalis can be analysed using titrations. Alkalis neutralise acids. An indicator is used to identify the point when neutralisation is just reached. During the reaction, hydrogen ions from the acid react with hydroxide ions from the alkali to form water. The reaction can be represented using the equation $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$</p> <p>As with all quantitative analysis techniques, titrations follow a standard procedure to ensure that the data is collected safely and is of high quality, including selecting samples, making rough and multiple repeat readings and using equipment of an appropriate precision (such as a burette and pipette).</p> <p>Data from titrations can be assessed in terms of its accuracy, precision and validity. An initial rough measurement is used as an estimate and titrations are repeated until a level of confidence can be placed in the data; the readings must be</p>	<ol style="list-style-type: none"> 1. explain how the mass of a solute and the volume of the solution is related to the concentration of the solution and calculate concentration using the formulae: $\text{concentration (g/dm}^3\text{)} = \frac{\text{mass of solute (g)}}{\text{volume (dm}^3\text{)}}$ M3c 2. explain how the concentration of a solution in mol/dm³ is related to the mass of the solute and the volume of the solution and calculate the molar concentration using the formula $\text{concentration (mol/dm}^3\text{)} = \frac{\text{number of moles of solute}}{\text{volume (dm}^3\text{)}}$ M3c 3. describe neutralisation as acid reacting with alkali to form a salt plus water including the common laboratory acids hydrochloric acid, nitric acid and sulfuric acid and the common alkalis, the hydroxides of sodium, potassium and calcium 4. recall that acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions

Linked learning opportunities**Specification links:**

- Strong and weak acid chemistry (C6.1)

Practical work:

- Making up a standard solution.

Practical work

- Acid-base titrations.
Use of appropriate measuring apparatus, measuring pH, use of a volumetric flask to make a standard solution, titrations using burettes and pipettes, use of acid-base indicators, safe handling of chemicals.

C5.3 How are the amounts of chemicals in solution measured?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>close together with a narrow range. The true value of a titration measurement can be estimated by discarding roughs and taking a mean of the results which are in close agreement.</p> <p>The results of a titration and the equation for the reaction are used to work out the concentration of an unknown acid or alkali.</p>	5. recognise that aqueous neutralisation reactions can be generalised to hydrogen ions reacting with hydroxide ions to form water
	6. describe and explain the procedure for a titration to give precise, accurate, valid and repeatable results
	7. evaluate the quality of data from titrations

Linked learning opportunities

Ideas about Science:

- Justify a technique in terms of precision, accuracy and validity of data to be collected, minimising risk. Use of range and mean when processing titration results, analysis of data (IaS1, IaS2).

Chapter C6: Making useful chemicals

Overview

This unit considers the laboratory and large scale production of useful chemicals. Topic C6.1 begins with the laboratory synthesis of salts from acid reactions, and also looks at the characteristics of both acids and bases.

In Topic C6.2, the story moves on to study how chemists manage the rate of reaction when these

reactions take place, in the context of managing conditions both in the laboratory and in industry. This topic gives the opportunity for a wide range of practical investigation and mathematical analysis of rates.

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

Learning about making useful chemicals before GCSE (9–1)

From study at Key Stages 1 to 3 Learners should:

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

Tiering

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

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

Learning about making useful chemicals at GCSE (9–1)

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Many products that we use every day are based on the chemistry of acid reactions. Products made using acids include cleaning products, pharmaceutical products and food additives. In addition, acids are made on an industrial scale to be used to make bulk chemicals such as fertilisers.</p> <p>Acids react in neutralisation reactions with metals, hydroxides and carbonates. All neutralisation reactions produce salts, which have a wide range of uses and can be made on an industrial scale.</p> <p>The strength of an acid depends on the degree of ionisation and hence the concentration of H^+ ions, which determines the reactivity of the acid. The pH of a solution is a measure of the concentration of H^+ ions in the solution. Strong acids ionise completely in solution, weak acids do not. Both strong and weak acids can be prepared at a range of different concentrations (i.e. different amounts of substance per unit volume).</p> <p>Weak acids and strong acids of the same concentration have different pH values. Weak acids are less reactive than strong acids of the same concentration (for example they react more slowly with metals and carbonates).</p>	<ol style="list-style-type: none"> recall that acids react with some metals and with carbonates and write equations predicting products from given reactants describe practical procedures to make salts to include appropriate use of filtration, evaporation, crystallisation and drying <i>PAGC4</i> use the formulae of common ions to deduce the formula of a compound recall that relative acidity and alkalinity are measured by pH including the use of universal indicator and pH meters use and explain the terms dilute and concentrated (amount of substance) and weak and strong (degree of ionisation) in relation to acids including differences in reactivity with metals and carbonates use the idea that as hydrogen ion concentration increases by a factor of ten the pH value of a solution decreases by one describe neutrality and relative acidity and alkalinity in terms of the effect of the concentration of hydrogen ions on the numerical value of pH (whole numbers only)

Linked learning opportunities

Specification links

- Writing formulae, balanced symbol and ionic equations (C3.2).
- Concentration of solutions (C5.4).

Practical work:

- Reactions of acids and preparation of salts.
- pH testing
- Investigating strong and weak acid reactivity.
- Use of indicators to test strong and weak acids, making standard solutions using volumetric flasks.

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

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

Linked learning opportunities

Specification links

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

Practical work:

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

Ideas about Science:

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

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Rate of reaction can be determined by measuring the rate at which a product is made or the rate at which a reactant is used. Some reactions involve a colour change or form a solid in a solution; the rate of these reactions can be measured by timing the changes that happen in the solutions by eye or by using apparatus such as a colorimeter. Reactions that make gases can be followed by measuring the volume of gas or the change in mass over time.</p> <p>On graphs showing the change in a variable such as concentration over time, the gradient of a tangent to the curve is an indicator of rate of change at that time. The average rate of a reaction can be calculated from the time taken to make a fixed amount of product.</p>	<p>7. suggest practical methods for determining the rate of a given reaction including: for reactions that produce gases: i) gas syringes or collection over water can be used to measure the volume of gas produced ii) mass change can be followed using a balance measurement of physical factors: iii) colour change iv) formation of a precipitate <i>PAGC5</i></p>
	<p>8. interpret rate of reaction graphs M4a, M4b</p>
	<p>9. use arithmetic computation and ratios when measuring rates of reaction M1a, M1c</p>
	<p>10. draw and interpret appropriate graphs from data to determine rate of reaction M2b, M4b, M4c</p>
	<p>11. determine gradients of graphs as a measure of rate of change to determine rate M4b, M4d, M4e</p>
	<p>12. use proportionality when comparing factors affecting rate of reaction M1c</p>

Linked learning opportunities

Practical work:

- Designing and carrying out investigations into rates. Analysing and interpreting data. Use of apparatus to make measurements. Use of heating equipment. Safe handling of chemicals. Measuring rates of reaction using two different methods.

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

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

Linked learning opportunities

Specification link:

- Enzymes in biological processes (B3.1).

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

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Industrial processes are managed to get the best yield as quickly and economically as possible. Chemists select the conditions that give the best economic outcome in terms of safety, maintaining the conditions and equipment, and energy use.</p> <p>The reactions in some processes are reversible. This can be problematic in industry because the reactants never completely react to make the products. This wastes reactants and means that the products have to be separated out from the reactants, which requires extra stages and costs.</p> <p>Data about yield and rate of chemical processes are used to choose the best conditions to make a product. On industrial scales, very high temperatures and pressures are expensive to maintain due to the cost of energy and because equipment may fail under extreme conditions. Catalysts can be used to increase the rate of reaction without affecting yield.</p> <p>Chemical engineers choose the conditions that will make the process as safe and efficient as possible, reduce the energy costs and reduce the waste produced at all stages of the process.</p>	<ol style="list-style-type: none"> recall that some reactions may be reversed by altering the reaction conditions including: <ol style="list-style-type: none"> reversible reactions are shown by the symbol \rightleftharpoons reversible reactions (in closed systems) do not reach 100% yield recall that dynamic equilibrium occurs when the rates of forward and reverse reactions are equal predict the effect of changing reaction conditions (concentration, temperature and pressure) on equilibrium position and suggest appropriate conditions to produce a particular product, including: <ol style="list-style-type: none"> catalysts increase rate but do not affect yield the disadvantages of using very high temperatures or pressures

Linked learning opportunities

Specification links:

- Calculations of yields (C5.1).

Practical work:

- Investigating reversible reactions.

Ideas about Science:

- Make predictions from data and graphs about yield of chemical products (IaS1).
- Consider the risks and costs of different operating conditions in an ammonia plant (IaS4).

Practical work

- Analyse and evaluate data about yield and rate of ammonia production.

Chapter P1: Radiation and waves

Overview

There are two key science ideas in this chapter – the first considers the uses of electromagnetic radiation and the possible health risks of radiation, both in nature and from technological devices, which are becoming of increasing concern. The second part of the chapter considers a wave model for light and sound.

Topic P1.1 describes the model of radiation, an important scientific model for explaining how one object can affect another at a distance, and links this to the idea that all parts of the electromagnetic spectrum behave in this way. It then goes on to use the radiation model to explain how electromagnetic radiation behaves and to consider the risks and benefits of the technologies that use electromagnetic radiation. In some cases, misunderstanding the term ‘radiation’ generates unnecessary alarm. Through considering the evidence concerning the possible

harmful effects of low intensity microwave radiation from devices such as mobile phones, learners learn to evaluate reported health studies and interpret levels of risk.

Topic P1.2 introduces the idea that all bodies emit radiation to explain the greenhouse effect. Evidence for global warming is explored; scientific explanations for climate change draw on ideas about the way that radiation is emitted and absorbed by different materials. There is an opportunity to use both physical analogies and computer modelling to demonstrate the explanatory power of models in science.

All waves have properties in common and a wave model can be used to explain a great many phenomena, both natural and artificial. In Topic P1.3 the reflection and refraction of waves on water provide evidence that light and sound can be modelled as waves.

Learning about light, sound, and waves, before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- have observed waves on water, spring, and strings
- know the meaning of the terms longitudinal, transverse, superposition, and frequency, in the context of waves
- know that sound waves are longitudinal and need a medium to travel through and that sound travels at different speeds in solids, in water, and in air
- know that sound is produced when objects vibrate and that sound waves are detected by the vibrations they cause
- know that light travels at a very high speed and can pass through a vacuum
- know some of the similarities and differences between light waves and waves in matter
- be able to use a ray model of light to describe and explain reflection in mirrors, refraction and dispersion by glass and the action of convex lenses
- know that light incident on a surface may be absorbed, scattered, or reflected, and that light transfers energy from a source to an absorber, where it may cause a chemical or electrical effect.

Tiering

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

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

Learning about light, sound and waves at GCSE (9–1)

P1.1 What are the risks and benefits of using radiations?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>A model of radiation can be used to describe and predict the effects of some processes in which one object affects another some distance away. One object (a source) emits radiation (of some kind). This spreads out from the source and transfers energy to other object(s) some distance away.</p> <p>Light is one of a family of radiations, called the electromagnetic spectrum. All radiations in the electromagnetic spectrum travel at the same speed through space.</p> <p>When radiation strikes an object, some may be transmitted (pass through it), or be reflected, or be absorbed. When radiation is absorbed it ceases to exist as radiation; usually it heats the absorber.</p> <p>Some types of electromagnetic radiation do not just cause heating when absorbed; X-rays, gamma rays and high energy ultraviolet radiation have enough energy to remove an electron from an atom or molecule (ionisation) which can then take part in other chemical reactions.</p>	1. describe the main groupings of the electromagnetic spectrum – radio, microwave, infrared, visible (red to violet), ultraviolet, X-rays and gamma rays, that these range from long to short wavelengths, from low to high frequencies, and from low to high energies
	2. recall that our eyes can only detect a very limited range of frequencies in the electromagnetic spectrum
	3. recall that all electromagnetic radiation is transmitted through space with the same very high (but finite) speed
	4. explain, with examples, that electromagnetic radiation transfers energy from source to absorber
	5. recall that different substances may absorb, transmit, or reflect electromagnetic radiation in ways that depend on wavelength
	6. recall that in each atom its electrons are arranged at different distances from the nucleus, that such arrangements may change with absorption or emission of electromagnetic radiation, and that atoms can become ions by loss of outer electrons

Linked learning opportunities

Practical work:

- Estimate the speed of microwaves using a microwave oven.
- Investigate how the intensity of radiation changes with distance from the source.

Specification links:

- Why are some materials radioactive? (P6.1)
- How can radioactive materials be used safely (P6.2).
- How has our understanding of the atom developed over time? (C2.1)

P1.1 What are the risks and benefits of using radiations?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Exposure to large amounts of ionising radiation can cause damage to living cells; smaller amounts can cause changes to cells which may make them grow in an uncontrolled way, causing cancer.</p> <p>Oxygen is acted on by radiation to produce ozone in the upper atmosphere. This ozone absorbs ultraviolet radiation, and protects living organisms, especially animals, from its harmful effects.</p> <p>Radio waves are produced when there is an oscillating current in an electrical circuit. Radio waves are detected when the waves cause an oscillating current in a conductor.</p> <p>Different parts of the electromagnetic spectrum are used for different purposes due to differences in the ways they are reflected, absorbed, or transmitted by different materials.</p> <p>Developments in technology have made use of all parts of the electromagnetic spectrum; every development must be evaluated for the potential risks as well as the benefits (IaS4). Data and scientific explanations of mechanisms, rather than opinion, should be used to justify decisions about new technologies (IaS3).</p>	<ol style="list-style-type: none"> 7. recall that changes in molecules, atoms and nuclei can generate and absorb radiations over a wide frequency range, including: <ol style="list-style-type: none"> a) gamma rays are emitted from the nuclei of atoms b) X-rays, ultraviolet and visible light are generated when electrons in atoms lose energy c) high energy ultraviolet, gamma rays and X-rays have enough energy to cause ionisation when absorbed by some atoms d) ultraviolet is absorbed by oxygen to produce ozone, which also absorbs ultraviolet, protecting life on Earth e) infrared is emitted and absorbed by molecules 8. describe how ultra-violet radiation, X-rays and gamma rays can have hazardous effects, notably on human bodily tissues 9. give examples of some practical uses of electromagnetic radiation in the radio, microwave, infrared, visible, ultraviolet, X-ray and gamma ray regions of the spectrum 10. recall that radio waves can be produced by, or can themselves induce, oscillations in electrical circuits

Linked learning opportunities

Ideas about Science:

- Use the radiation model to predict and explain the behaviour of electromagnetic radiation (IaS3).

Practical work

- Investigate absorption, transmission and reflection of electromagnetic radiation e.g. absorption of ultraviolet by sunscreens, reflection and absorption of microwaves, or mobile phone signals.

Ideas about Science

- Discuss the different risks and benefits of technologies that use electromagnetic radiation (IaS4).

P1.2 What is climate change and what is the evidence for it?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>All objects emit electromagnetic radiation with a principal frequency that increases with temperature. The Earth is surrounded by an atmosphere which allows some of the electromagnetic radiation emitted by the Sun to pass through; this radiation warms the Earth's surface when it is absorbed. The radiation emitted by the Earth, which has a lower principal frequency than that emitted by the Sun, is absorbed and re-emitted in all directions by some gases in the atmosphere; this keeps the Earth warmer than it would otherwise be and is called the greenhouse effect.</p> <p>One of the main greenhouse gases in the Earth's atmosphere is carbon dioxide, which is present in very small amounts; other greenhouse gases include methane, present in very small amounts, and water vapour. During the past two hundred years, the amount of carbon dioxide in the atmosphere has been steadily rising, largely the result of burning increased amounts of fossil fuels as an energy source and cutting down or burning forests to clear land.</p> <p>Computer climate models provide evidence that human activities are causing global warming. As more data is collected using a range of technologies, the model can be refined further and better predictions made (1a3).</p>	<ol style="list-style-type: none"> 1. explain that all bodies emit radiation, and that the intensity and wavelength distribution of any emission depends on their temperatures 2. explain how the temperature of a body is related to the balance between incoming radiation, absorbed radiation and radiation emitted; illustrate this balance, using everyday examples including examples of factors which determine the temperature of the Earth

Linked opportunities

Specification Links

- What is the evidence for climate change? (C1.2)

Practical work:

- Investigate climate change models – both physical models and computer models

Ideas about Science

- Use ideas about the way science explanations are developed when discussing climate change (1a3).
- Use ideas about correlation and cause when discussing evidence for climate change (1a3).

P1.3 How do waves behave?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>A wave is a regular disturbance that transfers energy in the direction that the wave travels, without transferring matter.</p> <p>For some waves (such as waves along a rope), the disturbance of the medium as the wave passes is at right-angles to its direction of motion. This is called a transverse wave. For other waves (such as a series of compression pulses on a slinky spring), the disturbance of the medium as the wave passes is parallel to its direction of motion. This is called a longitudinal wave.</p> <p>The speed of a wave depends on the medium it is travelling through. Its frequency is the number of waves each second that are made by the source. The wavelength of waves is the distance between the same points on two adjacent disturbances.</p> <p>The ways in which light and sound waves reflect and refract when they meet at an interface between two materials can be modelled with water waves.</p> <p>A wave model for light and sound can be used to describe and predict some behaviour of light and sound.</p> <p>Refraction of light and sound can be explained by a change in speed of waves when they pass into a different medium; a change in the speed of a wave causes a change in wavelength since the frequency of the waves cannot change, and that this may cause a change in direction.</p>	1. describe wave motion in terms of amplitude, wavelength, frequency and period
	2. describe evidence that for both ripples on water surfaces and sound waves in air, it is the wave and not the water or air itself that travels
	3. describe the difference between transverse and longitudinal waves
	4. describe how waves on a rope are an example of transverse waves whilst sound waves in air are longitudinal waves
	5. define wavelength and frequency
	6. recall and apply the relationship between speed, frequency and wavelength to waves, including waves on water, sound waves and across the electromagnetic spectrum: wave speed (m/s) = frequency (Hz) × wavelength (m) M1a, M1c, M3c, M3d
	7. a) describe how the speed of ripples on water surfaces and the speed of sound waves in air, may be measured b) describe how to use a ripple tank to measure the speed/frequency and wavelength of a wave PAGP4

Linked learning opportunities

Ideas about Science

- Use the wave model to predict and explain the observed behaviour of light (IaS3).

Practical work:

- Carry out experiments to measure the speed of waves on water and the speed of sound in air.

P1.3 How do waves behave?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	<p>8. a) describe the effects of reflection and refraction of waves at material interfaces</p> <p> b) describe how to measure the refraction of light through a prism</p> <p> c) describe how to investigate the reflection of light off a plane mirror</p> <p><i>PAGP4</i></p>
	<p>9. recall that waves travel in different substances at different speeds and that these speeds may vary with wavelength</p>
	<p>10. explain how refraction is related to differences in the speed of the waves in different substances</p>
	<p>11. recall that light is an electromagnetic wave</p>
	<p>12. recall that electromagnetic waves are transverse</p>

Linked learning opportunities

Chapter P2: Sustainable energy

Overview

Energy supply is one of the major issues that society must address in the immediate future.

Citizens are faced with complex choices and a variety of messages from energy supply companies, environmental groups, the media, scientists and politicians. Some maintain that renewable resources are capable of meeting our future needs, some advocate nuclear power, and some argue that drastic lifestyle changes are required. Decisions about energy use, whether at a personal or a national level, need to be informed by a quantitative understanding of the

situation, and this is an underlying theme of the chapter.

Topic P2.1 quantifies the energy used by electrical devices introduces calculations of efficiency and considers ways of reducing dissipation in a variety of contexts. In Topic P2.2 national data on energy sources introduces a study of electricity generation and distribution; nuclear power generation, the burning of fossil fuels and renewable resources are compared and contrasted. Electrical safety in the home and a review of the energy choices available to individuals, organisations and society are also included.

Learning about energy before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- have compared energy uses and costs in domestic contexts, including calculations using a variety of units
- have considered a variety of processes that involve transferring energy, including heating, changing motion, burning fuels and changing position in a field.

Tiering

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

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

Learning about energy at GCSE (9–1)

P2.1 How much energy do we use?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Energy is considered as being stored in a limited number of ways: chemical, nuclear, kinetic, gravitational, elastic, thermal, electrostatic and electromagnetic and can be transferred from one to another by processes called working and heating.</p> <p>Electricity is a convenient way to transfer energy from source to the consumer because it is easily transmitted over distances and can be used to do work in many ways, including heating and driving motors which make things move or to lift weights.</p> <p>When energy is used to do work some energy is usually wasted in doing things other than the intended outcome, it is dissipated into the surroundings, ultimately into inaccessible thermal stores.</p> <p>The power of an appliance or device is a measure of the amount of energy it transfers each second, i.e. the rate at which it transfers energy.</p> <p>Sankey diagrams are used to show all the energy transfers in a system, including energy dissipated to the surroundings; the data can be used to calculate the efficiency of energy transfers.</p>	1. describe how energy in chemical stores in batteries, or in fuels at the power station, is transferred by an electric current, doing work on domestic devices, such as motors or heaters
	2. explain, with reference to examples, the relationship between the power ratings for domestic electrical appliances, the time for which they are in use and the changes in stored energy when they are in use
	3. recall and apply the following equation in the context of energy transfers by electrical appliances: energy transferred (J, kWh) = power (W, kW) × time (s, h) M3c, M3d
	4. describe, with examples, where there are energy transfers in a system, that there is no net change to the total energy of a closed system <i>qualitative only</i>
	5. describe, with examples system changes, where energy is dissipated, so that it is stored in less useful ways
	6. explain ways of reducing unwanted energy transfer e.g. through lubrication, thermal insulation

Linked learning opportunities

Practical work

- Compare the power consumption of a variety of devices and relate it to the changes in stored energy.
- Investigate the effects of insulation on the rate of cooling.

Maths

- Calculate the cost of energy supplied by electricity given the power rating, the time and the cost per kWh (1aS2.2).

P2.1 How much energy do we use?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	7. describe the effects, on the rate of cooling of a building, of thickness and thermal conductivity of its walls <i>qualitative only</i>
	8. recall and apply the equation: $\text{efficiency} = \frac{\text{useful energy transferred}}{\text{total energy transferred}}$ to calculate energy efficiency for any energy transfer, and describe ways to increase efficiency M1c
	9. interpret and construct Sankey diagrams to show understanding that energy is conserved M4a

Linked learning opportunities

P2.2 How can electricity be generated?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The main energy resources that are available to humans are fossil fuels (oil, gas, coal), nuclear fuels, biofuels, wind, water, and radiation from the Sun.</p> <p>In most power stations generators produce a voltage across a wire by spinning a magnet near the wire. Often an energy source is used to heat water; the steam produced drives a turbine which is coupled to an electrical generator. Other energy sources drive the generator directly.</p> <p>The mains supply to our homes is an alternating voltage, at 50Hz, 230 volts, but electricity is distributed through the National Grid at much higher voltages to reduce energy losses. Transformers are used to increase the voltage for transmission and then decrease the voltage for domestic use.</p> <p>Most mains appliances are connected by a three core cable, containing live, neutral and earth wires.</p> <p>The demand for energy is continually increasing and this raises issues about the availability and sustainability of energy sources and the environmental effects of using these sources. The introduction and development of new energy sources may provide new opportunities but also introduces technological and environmental challenges. The decisions about the energy sources that are used may be different for different people in different contexts (1aS4).</p>	1. describe the main energy resources available for use on Earth (including fossil fuels, nuclear fuel, biofuel, wind, hydroelectricity, the tides and the Sun)
	2. explain the differences between renewable and non-renewable energy resources
	3. compare the ways in which the main energy resources are used to generate electricity M2c
	4. recall that the domestic supply in the UK is a.c., at 50Hz and about 230 volts and explain the difference between direct and alternating voltage
	5. recall that, in the National Grid, transformers are used to transfer electrical power at high voltages from power stations, to the network and then used again to transfer power at lower voltages in each locality for domestic use
	6. recall the differences in function between the live, neutral and earth mains wires, and the potential differences between these wires; hence explain that a live wire may be dangerous even when a switch in a mains circuit is open, and explain the dangers of providing any connection between the live wire and any earthed object
	7. explain patterns and trends in the use of energy resources in domestic contexts, workplace contexts, and national contexts M2c

Linked learning opportunities

Specification links

- What determines the rate of energy transfer in a circuit? (P3.4)
- **What is the process inside a generator? (P3.7)**

Practical work

- Investigate factors affecting the output from solar panels and wind turbines.

Maths

- Use ideas about probability in the context of risk.
- Extract and interpret information about electricity generation and energy use presented in a variety of numerical and graphical forms.

Ideas about Science

- Discuss the risks and benefits of different ways of generating electricity and why different decisions on the same issue might be appropriate (1aS4.3–4.9, 4.11).

Chapter P3: Electric circuits

Overview

Known only by its effects, electricity provides an ideal vehicle to illustrate the use and power of scientific models. During the course of the 20th century, electrical engineers completely changed whole societies, by designing systems for electrical generation and distribution, and a whole range of electrical devices.

In this chapter, learners learn how scientists visualise what is going on inside circuits and predict circuit behaviour. In Topic P3.1, models of charge moving through circuits driven by a voltage and against a resistance are introduced. A more general understanding of voltage as potential difference is then developed in Topic P3.2, which then continues

with an exploration of the difference between series and parallel circuits, leading on to investigating the behaviour of various components in d.c. series circuits. Topic P3.3 concentrates on quantifying the energy transferred in electric circuits and how this is determined by both the potential difference and the current.

A reminder of earlier work on magnets and magnetic fields in Topic P3.4 leads into an introduction to the electric motor in Topic P3.5. Applications of electromagnetism and in particular the electric motor have revolutionised people's lives in so many ways – from very small motors used in medical contexts, to very large motors used to propel ships or pump water in pumped storage schemes.

Learning about electricity and magnetism before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be familiar with the basic properties of magnets, and use these to explain and predict observations
- know that there is a magnetic field close to any wire carrying an electric current
- be aware of the existence of electric charge, and understand how simple electrostatic phenomena can be explained in terms of the movement of electrons between and within objects
- understand the idea of an electric circuit (a closed conducting loop containing a battery)
- that conducts an electric current and be able to predict the current in branches of a parallel circuit
- understand the idea of voltage as a measure of the 'strength' of a battery or power supply
- know that electrical resistance is measured in ohms and can be calculated by dividing the voltage across the component by the current through it
- know that the power ratings of electrical appliances are related to the rate at which the appliances transfers energy.

Tiering

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

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

Learning about electricity and magnetism at GCSE (9–1)

P3.1 What determines the current in an electric circuit?	
Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>An electric current is the rate of flow of charge; in an electric circuit the metal conductors (the components and wires) contain many charges that are free to move. When a circuit is made, the battery causes these free charges to move, and these charges are not used up but flow in a continuous loop.</p> <p>In a given circuit, the larger the potential difference across the power supply the bigger the current. Components (for example, resistors, lamps, motors) resist the flow of charge through them; the resistance of connecting wires is usually so small that it can be ignored. The larger the resistance in a given circuit, the smaller the current will be.</p> <p>Representational models of electric circuits use physical analogies to help think about how an electric circuit works, and to predict what happens when a variable is changed (IaS3).</p>	1. recall that current is a rate of flow of charge, that for a charge to flow, a source of potential difference and a closed circuit are needed and that a current has the same value at any point in a single closed loop
	2. recall and use the relationship between quantity of charge, current and time: charge (C) = current (A) × time (s) M1c, M3c, M3d
	3. recall that current (I) depends on both resistance (R) and potential difference (V), and recall the units in which these quantities are measured
	4. a) recall and apply the relationship between I , R , and V , to calculate the currents, potential differences and resistances in d.c. series circuits potential difference (V) = current (A) × resistance (Ω) M1c, M3c, M3d b) describe an experiment to investigate the resistance of a wire and be able to draw the circuit diagram of the circuit used PAGP6
	5. recall that for some components the value of R remains constant (fixed resistors) but that in others it can change as the current changes (e.g. heating elements, lamp filaments)

Linked learning opportunities

Ideas about Science

- Identify limitations in analogies used to represent electric circuits (IaS3)

Practical work

- Design and construct electric circuits to investigate the electrical properties of range of circuit components.

P3.1 What determines the current in an electric circuit?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	<p>6. a) use graphs to explore whether circuit elements are linear or non-linear and relate the curves produced to their function and properties M4c, M4d</p> <p> b) describe experiments to investigate the I-V characteristics of circuit elements. To include: lamps, diodes, LDRs and thermistors. Be able to draw circuit diagrams for the circuits used PAGP6</p>
	<p>7. represent circuits with the conventions of positive and negative terminals, and the symbols that represent common circuit elements, filament lamps, diodes, LDRs, thermistors, switches and fixed and variable resistors</p>

Linked learning opportunities

P3.2 How do series and parallel circuits work?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>When electric charge flows through a component (or device), work is done by the power supply and energy is transferred from it to the component and/or its surroundings. Potential difference measures the work done per unit charge.</p> <p>In a series circuit the charge passes through all the components, so the current through each component is the same and the work done on each unit of charge by the battery must equal the total work done by the unit of charge on the components. The potential difference (p.d.) is largest across the component with the greatest resistance and a change in the resistance of one component will result in a change in the potential differences across all the components.</p> <p>In a parallel circuit each charge passes through only one branch of the circuit, so the current through each branch is the same as if it were the only branch present and the work done by each unit of charge is the same for each branch and equal to the work done by the battery on each charge. The current is largest through the component with the smallest resistance, because the same battery p.d. causes a larger current to flow through a smaller resistance than through a bigger one.</p> <p>When two or more resistors are placed in series the effective resistance of the combination (equivalent resistance) is equal to the sum of their resistances, because the battery has to move charges through all of them.</p>	<ol style="list-style-type: none"> relate the potential difference between two points in the circuit to the work done on, or by, a given amount of charge as it moves between these points: $\text{potential difference (V)} = \frac{\text{work done (energy transferred) (J)}}{\text{charge (C)}}$ M1c, M3c, M3d <ol style="list-style-type: none"> describe the difference between series and parallel circuits: to include ideas about how the current through each component and the potential difference across each component is affected by a change in resistance of a component describe how to practically investigate the brightness of bulbs in series and parallel circuits. Be able to draw circuit diagrams for the circuits used <i>PAGP6</i> explain, why, if two resistors are in series the net resistance is increased, whereas with two in parallel the net resistance is decreased <i>qualitative only</i> solve problems for circuits which include resistors in series, using the concept of equivalent resistance M1c, M3c, M3d

Linked learning opportunities

Ideas about Science

- Link the features of a model or analogy to features in an electric circuit, identify evidence for specific aspects of a model and limitations in representations of a model (1aS3).

Practical work

- Use d.c. series circuits, including potential divider circuits to investigate the behaviour of a variety of components.
- Design and construct electric circuits to use a sensor for a particular purpose.

P3.2 How do series and parallel circuits work?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Two (or more) resistors in parallel provide more paths for charges to move along than either resistor on its own, so the effective resistance is less.</p> <p>Some components are designed to change resistance in response to changes in the environment e.g. the resistance of an LDR varies with light intensity, the resistance of a thermistor varies with temperature; these properties are used in sensing systems to monitor changes in the environment.</p>	<p>5. explain the design and use of d.c. series circuits for measurement and testing purposes including exploring the effect of:</p> <ul style="list-style-type: none"> a) changing current in filament lamps, diodes, thermistors and LDRs b) changing light intensity on an LDR c) changing temperature of a thermistor (NTC only)

Linked learning opportunities

P3.3 What determines the rate of energy transfer in a circuit?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The energy transferred when electric charge flows through a component (or device), depends on the amount of charge that passes and the potential difference across the component.</p> <p>The power rating (in watts, W) of an electrical device is a measure of the rate at which an electrical power supply transfers energy to the device and/or its surroundings. The rate of energy transfer depends on both the potential difference and the current. The greater the potential difference, the faster the charges move through the circuit, and the more energy each charge transfers.</p> <p>The National Grid uses transformers to step down the current for power transmission. The power output from a transformer cannot be greater than the power input, therefore if the current increases, the potential difference must decrease. Transmitting power with a lower current through the cables results in less power being dissipated during transmission.</p>	1. describe the energy transfers that take place when a system is changed by work done when a current flows through a component
	2. explain, with reference to examples, how the power transfer in any circuit device is related to the energy transferred from the power supply to the device and its surroundings over a given time: power (W) = energy (J) ÷ time (s) M1c, M3c, M3d
	3. recall and use the relationship between the potential difference across the component and the total charge to calculate the energy transferred in an electric circuit when a current flows through a component: energy transferred (work done) (J) = charge (C) × potential difference (V) M1c, M3c, M3d
	4. recall and apply the relationships between power transferred in any circuit device, the potential difference across it, the current through it, and its resistance: a) power (W) = potential difference (V) × current (A) b) power (W) = (current (A)) ² × resistance (Ω) M1c, M3c, M3d

Linked learning opportunities

Practical work

- Compare the power consumption of a variety of devices and relate it to the current passing through the device.

P3.3 What determines the rate of energy transfer in a circuit?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	<p>5. use the idea of conservation of energy to show that when a transformer steps up the voltage, the output current must decrease and vice versa select and use the equation:</p> $\text{potential difference across primary coil} \times \text{current in primary coil} = \text{potential difference across secondary coil} \times \text{current in secondary coil}$ <p>M1c, M3b, M3c, M3d</p>
	<p>6. explain how transmitting power at higher voltages is more efficient way to transfer energy</p>

Linked learning opportunities

P3.4 What are magnetic fields?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Around any magnet there is a region, called the magnetic field, in which another magnet experiences a force. The magnetic effect is strongest at the poles. The field gets gradually weaker with distance from the magnet.</p> <p>The direction and strength of a magnetic field can be represented by field lines. These show the direction of the force that would be experienced by the N pole of a small magnet, placed in the field.</p> <p>The magnetic field around the Earth, with poles near the geographic north and south, provides evidence that the core of the Earth is magnetic. The N-pole of a magnetic compass will point towards the magnetic north pole.</p> <p>Magnetic materials (such as iron and nickel) can be induced to become magnets by placing them in a magnetic field. When the field is removed permanent magnets retain their magnetisation whilst other materials lose their magnetisation.</p> <p>When there is an electric current in a wire, there is a magnetic field around the wire; the field lines form concentric circles around the wire. Winding the wire into a coil (solenoid) makes the magnetic field stronger, as the fields of each turn add together. Winding the coil around an iron core makes a stronger magnetic field and an electromagnet that can be switched on and off.</p> <p>The 19th-century discovery of this electromagnetic effect led quickly to the invention of a number of magnetic devices, including electromagnetic relays, which formed the basis of the telegraph system, leading to a communications revolution (IaS4.1).</p>	<ol style="list-style-type: none"> 1. describe the attraction and repulsion between unlike and like poles for permanent magnets 2. describe the characteristics of the magnetic field of a magnet, showing how strength and direction change from one point to another 3. explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic 4. describe the difference between permanent and induced magnets 5. describe how to show that a current can create a magnetic effect 6. describe the pattern and directions of the magnetic field around a conducting wire 7. recall that the strength of the field depends on the current and the distance from the conductor 8. explain how the magnetic effect of a solenoid can be increased

Linked learning opportunities

Specification links

- Sound waves (P1.4).

Practical work

- Use plotting compasses to map the magnetic field near a permanent bar magnet, between facing like/opposite poles of two magnets, a single wire, a flat coil of wire and a solenoid.
- Investigate the relationship between the number of turns on a solenoid and the strength of the magnetic field.

Ideas about Science

- Developments of electromagnets have led to major changes in people's lives, including applications in communications systems, MRI scanners and on cranes in scrapyards.

P3.5 How do electric motors work?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The magnetic fields of a current-carrying wire and a nearby permanent magnet will interact and the wire and magnet exert a force on each other. This is called the ‘motor effect’.</p> <p>If the current-carrying wire is placed at right angles to the magnetic field lines, the force will be at right angles to both the current direction and the lines of force of the field. The direction of the force can be inferred using Fleming’s left-hand rule.</p> <p>The size of the force is proportional to the length of wire in the field, the current and the strength of the field.</p> <p>The motor effect can result in a turning force on a rectangular current-carrying coil placed in a uniform magnetic field; this is the principle behind all electric motors.</p> <p>The invention and development of practical electric motors have made an impact on almost every aspect of daily life (1aS4.1).</p>	<ol style="list-style-type: none"> 1. describe the interaction forces between a magnet and a current-carrying conductor to include ideas about magnetic fields 2. show that Fleming’s left-hand rule represents the relative orientations of the force, the conductor and the magnetic field 3. select and apply the equation that links the force (F) on a conductor to the strength of the field (B), the size of the current (I) and the length of conductor (l) to calculate the forces involved $\text{force (N)} = \text{magnetic flux density (T)} \times \text{current (A)} \times \text{length of conductor (m)}$ M1b, M1c, M3c, M3d 4. explain how the force on a conductor in a magnetic field is used to cause rotation in the rectangular coil of a simple electric motor <i>① Detailed knowledge of the construction of motors not required</i>

Linked learning opportunities

Practical work

- Investigate the motor effect for a single wire in a magnetic field and apply the principles to build a simple electric motor.
- Build a simple electric motor and explain how it works.

Ideas about Science

- Describe and explain examples of uses of electric motors that have made significant improvements to people’s lives (1aS4.1).

Chapter P4: Explaining motion

Overview

Simple but counterintuitive concepts of forces and motion, developed by Galileo and Newton, can transform young people's insight into everyday phenomena. These ideas also underpin an enormous range of modern applications, including spacecraft, urban mass transit systems, sports equipment and rides at theme parks.

Topic P4.1 reviews the idea of forces: identifying, describing and using forces to explain simple situations. Topic P4.2 looks at how speed is measured and represented graphically and introduces the

vector quantities of velocity and displacement. The relationships between distance, speed, acceleration and time are an example of simple mathematical modelling that can be used to predict the speed and position of a moving object.

The relationship between forces and motion is developed in Topic P4.3, where resultant forces and changes in momentum are described. These ideas are then applied in the context of road safety.

Topic P4.4 considers how we can describe motion in terms of energy changes.

Learning about force and motion before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- describe motion using words and with distance–time graphs
- use the relationship $\text{average speed} = \text{distance} \div \text{time}$
- identify the forces when two objects in contact interact; pushing, pulling, squashing, friction, turning
- use arrows to indicate the different forces acting on objects, and predict the net force when two or more forces act on an object
- know that the forces due to gravity, magnetism and electric charge are all non-contact forces
- understand how the forces acting on an object can be used to explain its motion.

Tiering

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

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

Learning about forces and motion at GCSE (9–1)

P4.1 What are forces?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>Force arises from an interaction between two objects, and when two objects interact, both always experience a force and these two forces form an interaction pair. The two forces in an interaction pair are the same kind of force, equal in size and opposite in direction, and act on different objects (Newton's Third Law).</p> <p>Friction is the interaction between two surfaces that slide (or tend to slide) relative to each other: each surface experiences a force in the direction that prevents (or tends to prevent) relative movement.</p> <p>There is an interaction between an object and the surface it is resting on: the object pushes down on the surface, the surface pushes up on the object with an equal force, and this is called the normal contact force.</p> <p>In everyday situations, a downward force acts on every object, due to the gravitational attraction of the Earth. This is called its weight. It can be measured (in N) using a spring (or top-pan) balance. The weight of an object is proportional to its mass. Near the Earth's surface, the weight of a 1 kg object is roughly 10 N. The Earth's gravitational field strength is therefore 10 N/kg.</p> <p>Newton's insight that linked the force that causes objects to fall to Earth with the force that keeps the Moon in orbit around the Earth led to the first universal law of nature.</p>	1. recall and apply Newton's Third Law
	2. recall examples of ways in which objects interact: by gravity, electrostatics, magnetism and by contact (including normal contact force and friction)
	3. describe how examples of gravitational, electrostatic, magnetic and contact forces involve interactions between pairs of objects which produce a force on each object
	4. represent interaction forces as vectors
	5. define weight
	6. describe how weight is measured
	7. recall and apply the relationship between the weight of an object, its mass and the gravitational field strength: weight (N) = mass (kg) × gravitational field strength (N/kg) M1c, M3c

Linked opportunities**Practical work**

- Investigate the effect of different combinations of surfaces on the frictional forces.

Ideas about science

- Explain how Newton's discovery of the universal nature of gravity is an example of the role of imagination in scientific discovery. (IaS3).

P4.2 How can we describe motion?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>The motion of a moving object can be described using the speed the object is moving, the direction it is travelling and whether the speed is changing.</p> <p>The distance an object has travelled at a given moment is measured along the path it has taken.</p> <p>The displacement of an object at a given moment is its net distance from its starting point together with an indication of direction.</p> <p>The velocity of an object at a given moment is its speed at that moment, together with an indication of its direction.</p> <p>Distance and speed are scalar quantities; they give no indication of direction of motion.</p> <p>Displacement and velocity are vector quantities, and include information about the direction.</p> <p>In everyday situations, acceleration is used to mean the change in speed of an object in a given time interval.</p> <p>Distance–time graphs and speed–time graphs can be used to describe motion. The average speed can be calculated from the slope of a distance–time graph.</p> <p>The average acceleration of an object moving in a straight line can be calculated from a speed–time graph. The distance travelled can be calculated from the area under the line on a speed–time graph.</p>	1. recall and apply the relationship: average speed (m/s) = distance (m) ÷ time (s) M1a, M1c, M3b, M3c, M3d
	2. recall typical speeds encountered in everyday experience for wind, and sound, and for walking, running, cycling and other transportation systems
	3. a) make measurements of distances and times, and calculate speeds b) describe how to use appropriate apparatus and techniques to investigate the speed of a trolley down a ramp M2b, M2f PAGP3
	4. make calculations using ratios and proportional reasoning to convert units, to include between m/s and km/h M1c, M3c
	5. explain the vector–scalar distinction as it applies to displacement and distance, velocity and speed
	6. a) recall and apply the relationship: acceleration (m/s ²) = change in speed (m/s) ÷ time taken (s) M1c, M3b, M3c, M3d b) explain how to use appropriate apparatus and techniques to investigate acceleration PAGP3

Linked opportunities

Practical work:

- Use a variety of methods to measure distances, speeds and times and to calculate acceleration.
- Compare methods of measuring the acceleration due to gravity.

Ideas about Science

- Use mathematical and computational models to make predictions about the motion of moving objects (1aS3).
- Explore using simple computer models to predict motion of a moving object.

P4.2 How can we describe motion?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
The mathematical relationships between acceleration, speed, distance, and time are a simple example of a computational model. The model can be used to predict the speed and position of an object moving at constant speed or with constant acceleration.	7. select and apply the relationship: $(\text{final speed (m/s)})^2 - (\text{initial speed (m/s)})^2 = 2 \times \text{acceleration (m/s}^2) \times \text{distance (m)}$ M1a, M1c, M3b, M3c, M3d
	8. draw and use graphs of distances and speeds against time to determine the speeds and accelerations involved
	9. interpret distance–time and velocity–time graphs, including relating the lines and slopes in such graphs to the motion represented M4a, M4b, M4c, M4d
	10. Interpret enclosed areas in velocity–time graphs M4a, M4b, M4c, M4d, M4f
	11. recall the value of acceleration in free fall and calculate the magnitudes of everyday accelerations using suitable estimates of speeds and times M2h

Linked opportunities

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
When forces act on an object the resultant force is the sum of all the individual forces acting on it, taking their directions into account. If a resultant force acts on an object, it causes a change of momentum in the direction of the force. The size of the change of momentum of an object is proportional to the size of the resultant force acting on the object and to the time for which it acts (Newton's Second Law). For an object moving in a straight line: <ul style="list-style-type: none"> if the resultant force is zero, the object will move at constant speed in a straight line (Newton's First Law) if the resultant force is in the direction of the motion, the object will speed up (accelerate) if the resultant force is in the opposite direction to the motion, the object will slow down. In situations involving a change in momentum (such as a collision), the longer the duration of the impact, the smaller the average force for a given change in momentum. In situations where the resultant force on a moving object is not in the line of motion, the force will cause a change in direction.	<ol style="list-style-type: none"> describe examples of the forces acting on an isolated solid object or system describe, using free body diagrams, examples where several forces lead to a resultant force on an object and the special case of balanced forces (equilibrium) when the resultant force is zero <i>qualitative only</i> use scale drawings of vector diagrams to illustrate the resolution of two or more forces, in situations when there is a net force, or equilibrium ① Limited to parallel and perpendicular vectors only M4a, M5a, M5b recall and apply the equation for momentum and describe examples of the conservation of momentum in collisions: momentum (kg m/s) = mass (kg) × velocity (m/s) M1c, M3c, M3d select and apply Newton's Second Law in calculations relating force, change in momentum and time: change of momentum (kg m/s) = resultant force (N) × time for which it acts (s) M1c, M3c, M3d

Linked opportunities

Practical work

- Investigate factors that might affect human reaction times.
- Investigate the use of crumple zones to reduce the stopping forces.

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>If the force is perpendicular to the direction of motion the object will move in a circle at a constant speed – the speed doesn't change but the velocity does. For example, a planet in orbit around the Sun – gravity acts along the radius of the orbit, at right angles to the planet's path.</p> <p>The mass of an object can be thought of as the amount of matter in an object – the sum of all the atoms that make it up. Mass is measured in kilograms. The mass of an object is also a measure of its resistance to any change in its motion (its inertia); using this definition the inertial mass is the ratio of the force applied to the resulting acceleration.</p> <p>Newton wrote about how the length of time a force acted on an object would change the object's 'amount of motion', and the way he used the term makes it clear that he is describing what we now call momentum, this has led to Newton's Second Law being expressed in two ways: in terms of change in momentum and in terms of acceleration.</p> <p>Newton's explanation of motion is one of the great intellectual leaps of humanity. It is a good example of the need for creativity and imagination to develop a scientific explanation of something that had been observed and discussed for many years (IaS3).</p>	6. apply Newton's First Law to explain the motion of objects moving with uniform velocity and also the motion of objects where the speed and/or direction changes
	7. explain with examples that motion in a circular orbit involves constant speed but changing velocity <i>qualitative only</i>
	8. explain that inertial mass is a measure of how difficult it is to change the velocity of an object and that it is defined as the ratio of force over acceleration
	9. recall and apply Newton's Second Law, relating force, mass and acceleration: force (N) = mass (kg) × acceleration (m/s ²) M1c, M3c, M3d
	10. use and apply equations relating force, mass, velocity, acceleration and momentum to explain relationships between the quantities M3b, M3c, M3d

Linked opportunities

Ideas about Science

- Explain why Newton's explanation of motion is an example of the need for creative thinking in developing new scientific explanations (IaS3).

P4.3 What is the connection between forces and motion?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>Ideas about force and momentum can be used to explain road safety measures, such as stopping distances, car seatbelts, crumple zones, air bags, and cycle and motorcycle helmets.</p> <p>Improvements in technology based on Newton’s laws of motion (together with the development of new materials) have made all forms of travel much safer.</p>	11. explain methods of measuring human reaction times and recall typical results
	12. explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies and the implications for safety M2c
	13. explain the dangers caused by large decelerations

Linked opportunities

Ideas about Science

- Describe and explain examples of how application of Newton’s laws of motion has led developments in road safety (IaS4).
- Discuss people’s willingness to accept risk in the context of car safety and explain ways in which the risks can be reduced (IaS4).

P4.4 How can we describe motion in terms of energy transfers?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
<p>Energy is always conserved in any event or process. Energy calculations can be used to find out if something is possible and what will happen, but not explain why it happens.</p> <p>The store of energy of a moving object is called its kinetic energy.</p> <p>As an object is raised, its store of gravitational potential energy increases, and as it falls, its gravitational potential energy decreases.</p> <p>When a force moves an object, it does work on the object, energy is transferred to the object; when work is done by an object, energy is transferred from the object to something else, for example:</p> <ul style="list-style-type: none"> when an object is lifted to a higher position above the ground, work is done by the lifting force; this increases the store of gravitational potential energy when a force acting on an object makes its velocity increase, the force does work on the object and this results in an increase in its store of kinetic energy. <p>If friction and air resistance can be ignored, an object's store of kinetic energy changes by an amount equal to the work done on it by an applied force; in practice air resistance or friction will cause the gain in kinetic energy to be less than the work done on it by an applied force in the direction of motion, because some energy is dissipated through heating.</p>	<ol style="list-style-type: none"> describe the energy transfers involved when a system is changed by work done by forces including: <ol style="list-style-type: none"> to raise an object above ground level to move an object along the line of action of the force recall and apply the relationship to calculate the work done (energy transferred) by a force: $\text{work done (Nm or J)} = \text{force (N)} \times \text{distance (m) (along the line of action of the force)}$ M1a, M3c, M3d recall the equation and calculate the amount of energy associated with a moving object: $\text{kinetic energy (J)} = 0.5 \times \text{mass (kg)} \times (\text{speed (m/s)})^2$ M1a, M3c, M3d recall the equation and calculate the amount of energy associated with an object raised above ground level: $\text{gravitational potential energy (J)} = \text{mass (kg)} \times \text{gravitational field strength (N/kg)} \times \text{height (m)}$ M1a, M3c, M3d make calculations of the energy transfers associated with changes in a system, recalling relevant equations for mechanical processes M1a, M1c, M3c

Linked opportunities

Specification links:

- Sustainable energy (P2).**

Practical work

- Use datalogging software to calculate the efficiency of energy transfers when work is done on a moving object.
- Measure the work done by an electric motor lifting a load, and calculate the efficiency.

P4.4 How can we describe motion in terms of energy transfers?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be able to:</i>
Calculating the work done when climbing stairs or lifting a load, and the power output, makes a link back to the usefulness of electrical appliances for doing many everyday tasks.	6. calculate relevant values of stored energy and energy transfers; convert between newton-metres and joules M1c, M3c
	7. describe all the changes involved in the way energy is stored when a system changes, for common situations: including an object projected upwards or up a slope, a moving object hitting an obstacle, an object being accelerated by a constant force, a vehicle slowing down
	8. explain, with reference to examples, the definition of power as the rate at which energy is transferred (work done) in a system
	9. recall and apply the relationship: power (W) = energy transferred (J) ÷ time (s) M1a, M3c, M3d

Linked opportunities

Chapter P5 Radioactive materials

Overview

The terms 'radiation' and 'radioactivity' are often interchangeable in the public mind. Because of its invisibility, radiation is commonly feared. A more objective evaluation of risks and benefits is encouraged through developing an understanding of the many practical uses of radioactive materials.

Topic P5.1 begins by considering the evidence of a nuclear model of the atom, including Rutherford's alpha particle scattering experiment. It then uses the nuclear model to explain what happens during

radioactive decay. The properties of alpha, beta and gamma radiation are investigated and ideas about half-life are developed.

In Topic P5.2 learners learn about the penetration properties of ionising radiation which leads to a consideration of the use of radioactive materials in the health sector, and how they can be handled safely. In the context of health risks associated with irradiation and/or contamination by radioactive material, they also learn about the interpretation of data on risk.

Learning about radioactivity before GCSE (9–1)

There is no formal learning about radioactivity before Key Stage 4, but learners will have ideas about radioactivity, nuclear energy and radiation from everyday language. From Topic P1.2 learners should:

- recall that in each atom its electrons are arranged at different distances from the nucleus
- recall that gamma rays are emitted from the nuclei of atoms
- be able to describe how ionising radiation can have hazardous effects, notably on human bodily tissues.

Tiering

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

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

Learning about radioactivity at GCSE (9–1)

P5.1 What is radioactivity?	
Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>An atom has a nucleus, made of protons and neutrons, which is surrounded by electrons.</p> <p>The modern model of the atom developed over time as scientists rejected earlier models and proposed new ones to fit the currently available evidence.</p> <p>Each stage relied on scientists using reasoning to propose models which fitted the evidence available at the time. Models were rejected, modified and extended as new evidence became available (1aS3).</p> <p>After the discovery of the electron in the 19th century by Thomson, scientists imagined that atoms were small particles of positive matter with the negative electrons spread through, like currants in a cake.</p> <p>This was the model used until 1910 when the results of the Rutherford-Geiger-Marsden alpha particle scattering experiment provided evidence that a gold atom contains a small, massive, positive region (the nucleus).</p> <p>Atoms are small – about 10^{-10} m across, and the nucleus is at the centre, about a hundred-thousandth of the diameter of the atom.</p> <p>Each atom has a nucleus at its centre and that nucleus is made of protons and neutrons. For an element, the number of the protons is always the same but the number of neutrons may differ. Forms of the same element with different numbers of neutrons are called the isotopes of the element.</p>	1. describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with almost all of the mass in the nucleus
	2. describe how and why the atomic model has changed over time, to include the main ideas of Dalton, Thomson, Rutherford and Bohr
	3. recall the typical size (order of magnitude) of atoms and small molecules
	4. recall that atomic nuclei are composed of both protons and neutrons, and that the nucleus of each element has a characteristic positive charge
	5. recall that nuclei of the same element can differ in nuclear mass by having different numbers of neutrons, these are called isotopes
	6. use the conventional representation to show the differences between isotopes, including their identity, charge and mass
	7. recall that some nuclei are unstable and may emit alpha particles, beta particles, or neutrons, and electromagnetic radiation as gamma rays

Linked learning opportunities

Specification links

- How has our understanding of the structure of atoms developed over time? (C2.1)

Ideas about Science

- Explain how the development of the nuclear model of the atom is an example of how scientific explanations become accepted (1aS3).

Practical work

- Collect data to calculate the half-life of a radioactive isotope.
- Use a random event such as dice-throwing to model radioactive decay.

P5.1 What is radioactivity?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Interpreting the unexpected results of the Rutherford-Geiger-Marsden experiment required imagination to consider a new model of the atom.	8. relate emissions of alpha particles, beta particles, or neutrons, and gamma rays to possible changes in the mass or the charge of the nucleus, or both
Some substances emit ionising radiation all the time and are called radioactive. The ionising radiation (alpha, beta, gamma, and neutron) is emitted from the unstable nucleus of the radioactive atoms, which as a result become more stable.	9. use names and symbols of common nuclei and particles to write balanced equations that represent the emission of alpha, beta, gamma, and neutron radiations during radioactive decay M1b, M1c, M3c
Alpha particles consist of two protons and two neutrons, and beta particles are identical to electrons. Gamma radiation is very high frequency electromagnetic radiation.	10. explain the concept of half-life and how this is related to the random nature of radioactive decay
Radioactive decay is a random process. For each radioactive isotope there is a different constant chance that any nucleus will decay. Over time the activity of radioactive sources decreases, as the number of undecayed nuclei decreases.	11. calculate the net decline, expressed as a ratio, in a radioactive emission after a given (integral) number of half-lives M1c, M3d
The time taken for the activity to fall to half is called the half-life of the isotope and can be used to calculate the time it takes for a radioactive material to become relatively safe.	12. interpret activity-time graphs to find the half-life of radioactive materials M1c, M2g, M4a, M4c

Linked learning opportunities

P5.2: How can radioactive materials be used safely?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Ionising radiation can damage living cells and these may be killed or may become cancerous, so radioactive materials must be handled with care. In particular, a radioactive material taken into the body (contamination) poses a higher risk than the same material outside as the material will continue to emit ionising radiation until it leaves the body.</p> <p>Whilst ionising radiation can cause cancer, it can also be used for imaging inside the body and to kill cancerous cells.</p> <p>Doctors and patients need to consider the risks and benefits when using ionising radiation to treat diseases.</p>	1. recall the differences in the penetration properties of alpha particles, beta particles and gamma rays
	2. recall the differences between contamination and irradiation effects and compare the hazards associated with each of these
	3. describe the different uses of nuclear radiations for exploration of internal organs, and for control or destruction of unwanted tissue
	4. explain how ionising radiation can have hazardous effects, notably on human bodily tissues
	5. explain why the hazards associated with radioactive material differ according to the radiation emitted and the half-life involved

Linked learning opportunities

Specification links:

- What are the risks and benefits of using electromagnetic radiations? (P1.2)

Practical work

- Collect and interpret data to show the penetration properties of ionising radiations.

Ideas about Science

- Discuss ideas about correlation and cause in the context of links between ionising radiation and cancer (IaS3).
- Discuss the uses of ionising radiation, with reference to its risks and benefits (IaS4).

Chapter P6: Matter – models and explanations

Overview

Richard Feynman said: “If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little

imagination and thinking are applied.”
(*Six Easy Pieces*, p.4).

In this chapter the particle model described by Feynman is used to predict and explain some properties of matter. Topic P6.1 explores the relationship between energy and temperature and the ways in which energy transfer transforms matter. Topic P6.2 considers how the particle model explains the differences in densities between solids, liquids and gases and the effect of heating both in terms of temperature changes and changes of state. Topic P6.3 considers the behaviour of materials under stress and how the particle model can explain differences in behaviour.

Learning about matter and the particle model before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- be able to use a particulate model of matter to explain states of matter and changes of state
- have investigated stretching and compressing materials and identifying those that obey Hooke’s law
- be able to describe how the extension or compression of an elastic material changes as a force is applied, and make a link between the work done and energy transfer during compression or extension
- have investigated pressure in liquids and related this to floating and sinking
- be able to relate atmospheric pressure to the weight of air overhead.

Tiering

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

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

Learning about Matter at GCSE (9–1)

P6.1 How does energy transform matter?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
It took the insight of a number of eighteenth and nineteenth century scientists to appreciate that heat and work were two aspects of the same quantity, which we call energy. Careful experiments devised by Joule showed that equal amounts of mechanical work would always produce the same temperature rise.	1. a) define density b) describe how to determine the densities of solid and liquid objects using measurements of length, mass and volume M1c, M5c PAGP1
Energy can be supplied to raise the temperature of a substance by heating using a fuel, or an electric heater, or by doing work on the material.	2. recall and apply the relationship between density, mass and volume to changes where mass is conserved: $\text{density (kg/m}^3\text{)} = \text{mass (kg)} \div \text{volume (m}^3\text{)}$ M1a, M1b, M1c, M3c
Mass – the amount of matter in an object – depends on its volume and the density of the material of which it consists.	3. describe the energy transfers involved when a system is changed by heating (in terms of temperature change and specific heat capacity)
The temperature rise of an object when it is heated depends on its mass and the amount of energy supplied. Different substances store different amounts of energy per unit mass for the same temperature rise – this is called the specific heat capacity of the material.	4. define the term specific heat capacity and distinguish between it and the term specific latent heat
When a substance in the solid state is heated, its temperature rises until it reaches the melting point of the substance, but energy must continue to be supplied for the solid to melt. Its temperature does not change while it melts, and the change in density on melting is very small. Similarly as a substance in the liquid state is heated its temperature rises until it reaches boiling point; its temperature does not change, although energy continues to be supplied while it boils. The change in density on boiling is very great; a small volume of liquid produces a large volume of vapour.	5. a) select and apply the relationship between change in internal energy of a material and its mass, specific heat capacity and temperature: $\text{change in internal energy (J)} = \text{mass (kg)} \times \text{specific heat capacity (J / kg / }^\circ\text{C)} \times \text{change in temperature (}^\circ\text{C)}$ M1a, M1c, M3d b) explain how to safely use apparatus to determine the specific heat capacity of materials PAGP5

Linked learning opportunities

Specification links

- How much energy do we use? (P2.1)
- What determines the rate of energy transfer in a circuit (P3.4).
- How can we describe motion in terms of energy transfers (P4.4).

Practical work

- Devise a method to measure the density of irregular objects.
- Measure the specific heat capacity of a range of substances such as water, copper, aluminium.
- Measure the latent heat of fusion of a substance in the solid state and the latent heat of vaporisation of a substance in the liquid state.
- Show that the same amount of work always results in the same temperature rise.

P6.1 How does energy transform matter?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Different substances require different amounts of energy per kilogram to change the state of the substance – this is called the specific latent heat of the substance.	6. select and apply the relationship between energy needed to cause a change in state, specific latent heat and mass: energy to cause a change of state (J) = mass (kg) × specific latent heat (J/kg) M1a, M1c, M3c, M3d
	7. describe all the changes involved in the way energy is stored when a system changes, and the temperature rises, for example: a moving object hitting an obstacle, an object slowing down, water brought to a boil in an electric kettle
	8. make calculations of the energy transfers associated with changes in a system when the temperature changes, recalling or selecting the relevant equations for mechanical, electrical, and thermal processes M1a, M1c, M2a, M3c, M3d

Linked learning opportunities

- Collect data, plot and interpret graphs that show how the temperature of a substance changes when heated by a constant supply of energy.

Ideas about Science

- Describe and explain how careful experimental strategy can yield high quality data (IaS1).
- Describe and explain an example of how a developing a new scientific explanation takes creative thinking (IaS3).

P6.2 How does the particle model explain the effects of heating?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The particle model of matter describes the arrangements and behaviours of particles (atoms and molecules); it can be used to predict and explain the differences in properties between solids, liquids and gases. In this model:</p> <ul style="list-style-type: none"> all matter is made of very tiny particles there is no other matter except these particles (in particular, no matter between them) particles of any given substance are all the same particles of different substances have different masses there are attractive forces between particles. These differ in strength from one substance to another in the solid state, the particles are close together and unable to move away from their neighbours in the liquid state, the particles are also close together, but can slide past each other in the gas state, the particles are further apart, and can move freely. <p>The particle model is an example of how scientists use models as tools for explaining observed phenomena.</p>	1. explain the differences in density between the different states of matter in terms of the arrangements of the atoms or molecules
	2. use the particle model of matter to describe how mass is conserved, when substances melt, freeze, evaporate, condense or sublimate, but that these changes differ from chemical changes and the material recovers its original properties if the change is reversed
	3. use the particle model to describe how heating a system will change the energy stored within the system and raise its temperature or produce changes of state
	4. explain how the motion of the molecules in a gas is related both to its temperature and its pressure: hence explain the relation between the temperature of a gas and its pressure at constant volume <i>qualitative only</i>

Linked learning opportunities

Ideas about Science

- Use the particle model to explain familiar or unfamiliar phenomena and make predictions (1aS3).

P6.2 How does the particle model explain the effects of heating?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>	<i>Linked learning opportunities</i>
<p>The particle model can be used to describe and predict physical changes when matter is heated.</p> <ul style="list-style-type: none"> • The particles are always moving: in the solid state, they are vibrating; in the liquid state, they are vibrating and jostling around; in the gas state, they are moving freely in random directions. • A substance in the gas state exerts pressure on its container because the momentum of the particles changes when they collide with walls of the container. • The hotter something is, the higher its temperature is and the faster its particles are vibrating or moving. <p>Careful experimentation and mathematical analysis showed that the temperature of a substance was linked to the kinetic energy of its atoms or molecules.</p>		

P6.3 How does the particle model relate to materials under stress?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>When more than one force is applied to a solid material it may be compressed, stretched or twisted. When the forces are removed it may return to its original shape or become permanently deformed.</p> <p>These effects can be explained using ideas about particles in the solid state. A substance in the solid state is a fixed shape due to the forces between the particles.</p> <p>Compressing or stretching the material changes the separation of the particles, and the forces between the particles.</p> <p>Elastic materials spring back to their original shape. If the forces are too large the material becomes plastic and is permanently distorted.</p> <p>For some materials, the extension is proportional to the applied force, but in other systems, such as rubber bands the relationship is not linear, even though they are elastic.</p> <p>When work is done by a force to compress or stretch a spring or other simple system, energy is stored, this energy can be recovered when the force is removed.</p>	1. explain, with examples, that to stretch, bend or compress an object, more than one force has to be applied
	2. describe and use the particle model to explain the difference between elastic and plastic deformation caused by stretching forces
	3. a) describe the relationship between force and extension for a spring and other simple systems b) describe how to measure and observe the effect of forces on the extension of a spring M2b, M2f PAGP2
	4. describe the difference between the force-extension relationship for linear systems and for non-linear systems
	5. recall and apply the relationship between force, extension and spring constant for systems where the force-extension relationship is linear force exerted by a spring (N) = extension (m) × spring constant (N/m) M1c, M3c
	6. a) calculate the work done in stretching a spring or other simple system, by calculating the appropriate area on the force-extension graph M4f b) describe how to safely use apparatus to determine the work done in stretching a spring PAGP2

Linked learning opportunities

Practical work

- Investigate the force-extension properties of a variety of materials, identifying those that obey Hooke's law, those that behave elastically, and those that show plastic deformation.

P6.3 How does the particle model relate to materials under stress?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
	<p>7. select and apply the relationship between energy stored, spring constant and extension for a linear system: energy stored in a stretched spring (J) = $\frac{1}{2} \times \text{spring constant (N/m)} \times (\text{extension(m)})^2$</p> <p>M1c, M3b, M3c, M3d</p>

Linked learning opportunities

Chapter BCP7: Ideas about Science

Overview

In order to make sense of the scientific ideas that learners encounter in lessons and in everyday life outside of school, they need an understanding of how science explanations are developed, the kinds of evidence and reasoning behind them, their strengths and limitations, and how far we can rely on them.

Learners also need opportunities to consider the impacts of science and technology on society, and how we respond individually and collectively to new ideas, artefacts and processes that science makes possible.

It is intended that the *Ideas about Science* will help learners understand how scientific knowledge is obtained, how to respond to science stories and issues in the world outside the classroom, and the impacts of scientific knowledge on society.

Note that:

- although particular *Ideas about Science* have been linked to particular contexts throughout the specification as examples, the assessable learning outcomes in this chapter should be developed, and will be assessed, in any context from chapters B1–B6, C1–C6, and P1–P6.
- the assessable learning outcomes in this chapter will be assessed in all of the written examination papers
- terms associated with measurement and data analysis are used in accordance with their definitions in the Association of Science Education publication *The Language of Measurement* (2010).

Learning about How Science Works before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- understand that science explanations are based on evidence and that as new evidence is gathered, explanations may change
- have devised and carried out scientific enquiries, in which they have selected the most appropriate techniques and equipment, collected and analysed data and drawn conclusions.

Tiering

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

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

IaS1 What needs to be considered when investigating a phenomenon scientifically?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The aim of science is to develop good explanations for natural phenomena. There is no single ‘scientific method’ that leads to good explanations, but scientists do have characteristic ways of working. In particular, scientific explanations are based on a cycle of collecting and analysing data.</p> <p>Usually, developing an explanation begins with proposing a hypothesis. A hypothesis is a tentative explanation for an observed phenomenon (“this happens because...”).</p> <p>The hypothesis is used to make a prediction about how, in a particular experimental context, a change in a factor will affect the outcome. A prediction can be presented in a variety of ways, for example in words or as a sketch graph.</p> <p>In order to test a prediction, and the hypothesis upon which it is based, it is necessary to plan an experimental strategy that enables data to be collected in a safe, accurate and repeatable way.</p>	1. in given contexts use scientific theories and tentative explanations to develop and justify hypotheses and predictions
	2. suggest appropriate apparatus, materials and techniques, justifying the choice with reference to the precision, accuracy and validity of the data that will be collected
	3. recognise the importance of scientific quantities and understand how they are determined
	4. identify factors that need to be controlled, and the ways in which they could be controlled
	5. suggest an appropriate sample size and/or range of values to be measured and justify the suggestion M2d
	6. plan experiments or devise procedures by constructing clear and logically sequenced strategies to: <ul style="list-style-type: none"> – make observations – produce or characterise a substance – test hypotheses – collect and check data – explore phenomena
	7. identify hazards associated with the data collection and suggest ways of minimizing the risk
	8. use appropriate scientific vocabulary, terminology and definitions to communicate the rationale for an investigation and the methods used using diagrammatic, graphical, numerical and symbolic forms

Linked learning opportunities

Making and testing predictions:

Trends and patterns in the Periodic Table (C2)

Reactivity of metals (C3.2)

1aS2 What processes are needed to draw conclusions from data?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>The cycle of collecting, presenting and analysing data usually involves translating data from one form to another, mathematical processing, graphical display and analysis; only then can we begin to draw conclusions.</p> <p>A set of repeat measurements can be processed to calculate a range within which the true value probably lies and to give a best estimate of the value (mean).</p> <p>Displaying data graphically can help to show trends or patterns, and to assess the spread of repeated measurements.</p> <p>Mathematical comparisons between results and statistical methods can help with further analysis.</p>	1. present observations and other data using appropriate formats
	2. when processing data use SI units where appropriate (e.g. kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate
	3. when processing data use prefixes (e.g. tera, giga, mega, kilo, centi, milli, micro and nano) and powers of ten for orders of magnitude
	4. be able to translate data from one form to another M2c, M4a
	5. when processing data interconvert units
	6. when processing data use an appropriate number of significant figures M2a
	7. when displaying data graphically select an appropriate graphical form, use appropriate axes and scales, plot data points correctly, draw an appropriate line of best fit, and indicate uncertainty (e.g. range bars) M2c, M4a, M4c
	8. when analysing data identify patterns/trends, use statistics (range and mean) and obtain values from a line on a graph (including gradient, interpolation and extrapolation), M2b, M2f, M2g, M4b, M4d, M4e, M4f

Linked learning opportunities

P6.2 (mechanical equivalent of heat)

Describe and explain how careful experimental strategy can yield high quality data.

1a2 What processes are needed to draw conclusions from data?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Data obtained must be evaluated critically before we can make conclusions based on the results. There could be many reasons why the quality (accuracy, precision, repeatability and reproducibility) of the data could be questioned, and a number of ways in which they could be improved.</p> <p>Data can never be relied on completely because observations may be incorrect and all measurements are subject to uncertainty (arising from the limitations of the measuring equipment and the person using it). A result that appears to be an outlier should be treated as data, unless there is a reason to reject it (e.g. measurement or recording error)</p>	<p>9. in a given context evaluate data in terms of accuracy, precision, repeatability and reproducibility, identify potential sources of random and systematic error, and discuss the decision to discard or retain an outlier</p>
	<p>10. evaluate an experimental strategy, suggest improvements and explain why they would increase the quality (accuracy, precision, repeatability and reproducibility) of the data collected, and suggest further investigations</p>
<p>Agreement between the collected data and the original prediction increases confidence in the tentative explanation (hypothesis) upon which the prediction is based, but does not prove that the explanation is correct. Disagreement between the data and the prediction indicates that one or other is wrong, and decreases our confidence in the explanation.</p>	<p>11. in a given context interpret observations and other data (presented in diagrammatic, graphical, symbolic or numerical form) to make inferences and to draw reasoned conclusions, using appropriate scientific vocabulary and terminology to communicate the scientific rationale for findings and conclusions</p>
	<p>12. explain the extent to which data increase or decrease confidence in a prediction or hypothesis</p>

Linked learning opportunities

Drawing conclusions from data:

Patterns in the Periodic Table (C2)

Properties of polymers (C4.2)

1aS3 How are scientific explanations developed?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Scientists often look for patterns in data as a means of identifying correlations that can suggest cause-effect links – for which an explanation might then be sought.</p> <p>The first step is to identify a correlation between a factor and an outcome. The factor may then be the cause, or one of the causes, of the outcome. In many situations, a factor may not always lead to the outcome, but increases the chance (or the risk) of it happening. In order to claim that the factor causes the outcome we need to identify a process or mechanism that might account for the observed correlation.</p>	<ol style="list-style-type: none"> 1. use ideas about correlation and cause to: <ul style="list-style-type: none"> – identify a correlation in data presented as text, in a table, or as a graph M2g – distinguish between a correlation and a cause-effect link – suggest factors that might increase the chance of a particular outcome in a given situation, but do not invariably lead to it – explain why individual cases do not provide convincing evidence for or against a correlation – identify the presence (or absence) of a plausible mechanism as reasonable grounds for accepting (or rejecting) a claim that a factor is a cause of an outcome
<p>Scientific explanations and theories do not ‘emerge’ automatically from data, and are separate from the data. Proposing an explanation involves creative thinking. Collecting sufficient data from which to develop an explanation often relies on technological developments that enable new observations to be made.</p> <p>As more evidence becomes available, a hypothesis may be modified and may eventually become an accepted explanation or theory.</p> <p>A scientific theory is a general explanation that applies to a large number of situations or examples (perhaps to all possible ones), which has been tested and used successfully, and is widely accepted by scientists. A scientific explanation of a specific event or phenomenon is often based on applying a scientific theory to the situation in question.</p>	<ol style="list-style-type: none"> 2. describe and explain examples of scientific methods and theories that have developed over time and how theories have been modified when new evidence became available

Linked learning opportunities

Considering correlation and cause:

Evidence for risks of X-rays (P1.2)

Evidence for human activities causing global warming (P1.3)

Risk factors for non-communicable disease (B2.4)

Identifying causal relationships to explain climate change (C1.2).

Developing scientific explanations:

Climate change (P1.3)

Big Bang model (P4.5)

Nuclear model of the atom (P5.1)

The link between work, heat and temperature (P6.2)

The theory of natural selection (B6.1)

Explanatory accounts of how the atmosphere was formed (C1.1)

1a3 How are scientific explanations developed?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
<p>Findings reported by an individual scientist or group are carefully checked by the scientific community before being accepted as scientific knowledge. Scientists are usually sceptical about claims based on results that cannot be reproduced by anyone else, and about unexpected findings until they have been repeated (by themselves) or reproduced (by someone else).</p> <p>Two (or more) scientists may legitimately draw different conclusions about the same data. A scientist's personal background, experience or interests may influence his/her judgments.</p> <p>An accepted scientific explanation is rarely abandoned just because new data disagree with it. It usually survives until a better explanation is available.</p>	<p>3. describe in broad outline the 'peer review' process, in which new scientific claims are evaluated by other scientists</p>
<p>Models are used in science to help explain ideas and to test explanations. A model identifies features of a system and rules by which the features interact. It can be used to predict possible outcomes. Representational models use physical analogies or spatial representations to help visualise scientific explanations and mechanisms. Descriptive models are used to explain phenomena. Mathematical models use patterns in data of past events, along with known scientific relationships, to predict behaviour; often the calculations are complex and can be done more quickly by computer.</p> <p>Models can be used to investigate phenomena quickly and without ethical and practical limitations, but their usefulness is limited by how accurately the model represents the real world.</p>	<p>4. use a variety of models (including representational, spatial, descriptive, computational and mathematical models) to:</p> <ul style="list-style-type: none"> – solve problems – make predictions – develop scientific explanations and understanding – identify limitations of models

Linked learning opportunities

Explanations that relied on technological development:

Telescopes and the Big Bang model (P4.5)

Roles of cell organelles (B4.2)

Development of nano particles, and graphene (C4.3)

Examples of models:

Radiation model of light (P1.2)

Wave model of light (P1.3)

Equations of motion(P4.2)

Atomic model (P5.1)

Particle model of matter (P6.1, P6.2)

Lock and key for enzyme action (B3.1)

Using models of structure of materials to explain properties (C3.1, C4.1, C4.2, C4.3).

IaS4 How do science and technology impact society?

Teaching and learning narrative	Assessable learning outcomes <i>Learners will be required to:</i>
Science and technology provide people with many things that they value, and which enhance their quality of life. However some applications of science can have unintended and undesirable impacts on the quality of life or the environment. Scientists can devise ways of reducing these impacts and of using natural resources in a sustainable way (at the same rate as they can be replaced).	1. describe and explain everyday examples and technological applications of science that have made significant positive differences to people's lives
Everything we do carries a certain risk of accident or harm. New technologies and processes can introduce new risks.	2. identify examples of risks that have arisen from a new scientific or technological advance
The size of a risk can be assessed by estimating its chance of occurring in a large sample, over a given period of time.	3. for a given situation: <ul style="list-style-type: none"> – identify risks and benefits to the different individuals and groups involved – discuss a course of action, taking account of who benefits and who takes the risks – suggest reasons for people's willingness to accept the risk – distinguish between perceived and calculated risk
To make a decision about a course of action, we need to take account of both the risks and benefits to the different individuals or groups involved. People are generally more willing to accept the risk associated with something they choose to do than something that is imposed, and to accept risks that have short-lived effects rather than long-lasting ones. People's perception of the size of a particular risk may be different from the statistically estimated risk. People tend to over-estimate the risk of unfamiliar things (like flying as compared with cycling), and of things whose effect is invisible or long-term (like ionising radiation).	4. suggest reasons why different decisions on the same issue might be appropriate in view of differences in personal, social, economic or environmental context, and be able to make decisions based on the evaluation of evidence and arguments
Some forms of scientific research, and some applications of scientific knowledge, have ethical implications. In discussions of ethical issues, a common argument is that the right decision is one which leads to the best outcome for the greatest number of people.	5. distinguish questions that could in principle be answered using a scientific approach, from those that could not; where an ethical issue is involved clearly state what the issue is and summarise the different views that may be held
Scientists must communicate their work to a range of audiences, including the public, other scientists, and politicians, in ways that can be understood. This enables decision-making based on information about risks, benefits, costs and ethical issues.	6. explain why scientists should communicate their work to a range of audiences.

Linked learning opportunities

Positive applications of science:

Use of the electromagnetic spectrum (P1.2)

Generating and distributing electricity (P3.3)

Genetic engineering (B1.3)

Infertility treatment (B5.5)

Catalytic converters, low sulfur petrol and gas scrubbers (C1.1)

Sustainability:

Energy demands and choices of sources to generate electricity (P3.2)

Life cycle assessment (C4.4)

Risks, benefits and ethical issues:

Biodiversity (B6.4)
technologies that use ionising radiation (P1.2, P5.2)

Gene technology (B1.3)

Managing global warming (C1.2)

Chapter BCP8: Practical skills

Compliance with the requirements for practical work

It is compulsory that learners complete at least *sixteen* practical activities.

OCR has split the requirements from the Department for Education 'GCSE subject content and assessment objectives' – Appendix 4 into sixteen Practical Activity Groups or PAGs, *five biology, five chemistry and six physics*.

The Practical Activity Groups allow centres flexibility in their choice of activity. Whether centres use OCR suggested practicals or centre-substituted practicals, they must ensure completion of at least sixteen practical activities and each learner *must* have had the opportunity to use all of the apparatus and techniques described in the following tables of this chapter.

The tables illustrate the apparatus and techniques required for each PAG and an example practical that may be used to contribute to the PAG. It should be noted that some apparatus and techniques can be used in more than one PAG. *It is therefore important that teachers take care to ensure that learners do have the opportunity to use all of the required apparatus and techniques during the course with the activities chosen by the centre.*

Within the specification there are a number of practicals that are described in the 'Assessable

learning outcomes' column. These can count towards each PAG. We are expecting that centres will provide learners with opportunities to carry out a wide range of practical activities during the course. These can be the ones described in the specification or can be practicals that are devised by the centre. Activities can range from whole investigations to simple starters and plenaries.

It should be noted that the practicals described in the specification need to be covered in preparation for the questions in the written examinations that will assess practical skills. No less than 15% of the questions will assess practical skills. Learners also need to be prepared to answer questions using their knowledge and understanding of practical techniques and procedures in written papers.

Safety is an overriding requirement for all practical work. Centres are responsible for ensuring appropriate safety procedures are followed whenever their learners complete practical work.

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.

Revision of the requirements for practical work

OCR will review the practical activities detailed in Chapter BCP8 of this specification following any revision by the Secretary of State of the apparatus or techniques published specified in respect of the GCSE Combined Science B (Twenty First Century Science) qualification.

OCR will revise the practical activities if appropriate.

If any revision to the practical activities is made, OCR will produce an amended specification which will be published on the OCR website. OCR will then use the following methods to communicate the amendment to Centres: Notice to Centres sent to all Examinations Officers, e-alerts to Centres that have registered to teach the qualification and social media.

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.

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable biology activity (a range of practicals are included in the specification and centres can devise their own activity) *
B1 Microscopy	Use of appropriate apparatus, techniques and magnification, including microscopes, to make observations of biological specimens and produce labelled scientific drawings ⁷	Investigate different magnification techniques to draw scientific diagrams from a number of biological specimens.
	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 ¹	
B2 Sampling techniques	Application of appropriate sampling techniques to investigate the distribution and abundance of organisms in an ecosystem via direct use in the field (to include: biotic and abiotic factors)	Investigation the differences in habitats using ecological sampling techniques.
	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 ¹	
B3 Rates of enzyme-controlled reactions	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater ²	Investigate the factors that can affect the rate of enzyme activity.
	Use of appropriate apparatus and techniques for the observation and measurement of biological changes and/or processes ³	
	Measurement of rates of reaction by a variety of methods including production of gas, uptake of water and colour change of indicator ⁵	
	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 ¹	
B4 Photosynthesis	Use of appropriate apparatus and techniques for the observation and measurement of biological changes and/or processes ³	Investigate the factors that can affect the rate of photosynthesis on <i>Cabomba</i>
	Safe and ethical use of living organisms (plants or animals) to measure physiological functions and responses to the environment	
	Measurement of rates of reaction by a variety of methods including production of gas, uptake of water and colour change of indicator ⁵	
	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater ²	
	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 ¹	

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable biology activity (a range of practicals are included in the specification and centres can devise their own activity) *
B5 Microbiological techniques	Use of appropriate apparatus and techniques for the observation and measurement of biological changes and/or processes ³	Investigate the effectiveness of antimicrobial agents on the growth of a bacterial lawn.
	Use of appropriate apparatus, techniques and magnification, including microscopes, to make observations of biological specimens and produce labelled scientific drawings ⁷	
	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater ²	
	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 ¹	

* Centres are free to substitute alternative practical activities that also cover the apparatus and techniques from DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

^{1, 2, 3, 5, 7} These apparatus and techniques may be covered in any of the groups indicated. Number corresponds to that used in DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

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.

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable chemistry activity (a range of practicals are included in the specification and centres can devise their own activity) *
C1 Electrolysis	Use of appropriate apparatus and techniques to draw, set up and use electrochemical cells for separation and production of elements and compounds	Electrolysis of aqueous sodium chloride or aqueous copper sulfate solution testing for the gases produced
C2 Distillation	Safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, filtration, crystallisation, chromatography and distillation ⁴	Distillation of a mixture, for example orange juice, cherry cola, hydrocarbons, inks
	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater ²	
	Use of appropriate apparatus to make and record a range of measurements accurately, including mass, time, temperature, and volume of liquids and gases ¹	
C3 Separation Techniques	Safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, filtration, crystallisation, chromatography and distillation ⁴	Using chromatography to identify the mixtures of dyes in a sample of an unknown composition
C4 Production of salts	Safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, filtration, crystallisation, chromatography and distillation ⁴	Production of a pure dry sample of an insoluble and soluble salt
	Use of appropriate apparatus to make and record a range of measurements accurately, including mass, time, temperature, and volume of liquids and gases ¹	
	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	
	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	
	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater ²	

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable chemistry activity (a range of practicals are included in the specification and centres can devise their own activity) *
C5 Measuring rates of reaction	Use of appropriate apparatus to make and record a range of measurements accurately, including mass, time, temperature, and volume of liquids and gases ¹	Investigate the effect of surface area, concentration and temperature on the rate of a chemical reaction
	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	

* Centres are free to substitute alternative practical activities that also cover the apparatus and techniques from DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

^{1, 2, 4} These apparatus and techniques may be covered in any of the groups indicated. Number corresponds to that used in DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

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.

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable physics activity (a range of practicals are included in the specification and centres can devise their own activity)*
P1 Materials	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature ¹	Determine the densities of a variety of objects, both solid and liquid
	Use of such measurements to determine densities of solid and liquid objects	
P2 Forces	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature ¹	Investigate the effect of forces on springs
	Use of appropriate apparatus to measure and observe the effects of forces including the extension of springs	
P3 Motion	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature ¹	Investigate acceleration of a trolley down a ramp
	Use of appropriate apparatus and techniques for measuring motion, including determination of speed and rate of change of speed (acceleration/deceleration)	
P4 Waves	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature ¹	Use of a ripple tank to measure the speed, frequency and wavelength of a wave
	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.	Investigate the reflection of light off a plane mirror and the refraction of light through prisms
P5 Energy	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature ¹	Determine the specific heat capacity of a material
	Safe use of appropriate apparatus in a range of contexts to measure energy changes/transfers and associated values such as work done	

Practical Activity Group (PAG)	Apparatus and techniques that the practical must use or cover	Example of a suitable physics activity (a range of practicals are included in the specification and centres can devise their own activity)*
P6 Circuits	Use of appropriate apparatus to measure current, potential difference (voltage) and resistance, and to explore the characteristics of a variety of circuit elements	Investigate the I-V characteristics of circuit elements
	Use of circuit diagrams to construct and check series and parallel circuits including a variety of common circuit elements	

* Centres are free to substitute alternative practical activities that also cover the apparatus and techniques from DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

¹ These apparatus and techniques may be covered in any of the groups indicated. Number corresponds to that used in DfE: *Combined Science GCSE subject content, July 2015 Appendix 4*.

Choice of activity

Centres can include additional apparatus and techniques within an activity beyond those listed as the minimum in the above tables. Learners *must* complete a *minimum* of sixteen practicals covering all the apparatus and techniques listed.

The apparatus and techniques can be covered:

- (i) by using OCR suggested activities (provided as resources)
- (ii) through activities devised by the Centre.

Centres can receive guidance on the suitability of their own practical activities through our free coursework consultancy service.

Email: ScienceGCSE@ocr.org.uk

Where Centres devise their own practical activities to cover the apparatus and techniques listed above, the practical must cover all the requirements and be of a level of demand appropriate for GCSE. Each set of apparatus and techniques described in the middle column can be covered by more than one Centre devised practical activity e.g. “measurement of rates of reaction by a variety of methods including production of gas, uptake of water and colour change of indicator” could be split into two or more activities (rather than one).

NEA Centre Declaration Form: Practical Science Statement

Centres must provide a written **practical science statement** confirming that reasonable opportunities have been provided to all learners being submitted for entry within that year’s set of assessments to undertake at least **sixteen** practical activities.

The practical science statement is contained within the NEA Centre Declaration Form which can be found on the OCR website at www.ocr.org.uk/formsfinder. By signing the form, the centre is confirming that they have taken reasonable steps to secure that each learner:

- a) has completed the practical activities set by OCR as detailed in Chapter BCP8
- b) has made a contemporaneous record of:
 - (i) the work which the learner has undertaken during those practical activities, and
 - (ii) the knowledge, skills and understanding which that learner has derived from those practical activities.

Centres should retain records confirming points (a) to (b) above as they may be requested as part of the JCQ inspection process. Centres must provide practical science opportunities for their learners. This does not go so far as to oblige centres to ensure that all of their learners take part in all of the practical science opportunities. There is always a risk that an individual learner may miss the arranged practical science work, for example because of illness. It could be costly for the centre to run additional practical science opportunities for the learner.

However, the opportunities to take part in the specified range of practical work must be given to all learners. Learners who do not take up the full range of opportunities may be disadvantaged as there will be questions on practical science in the GCSE (9–1) Combined Science B (Twenty First Century Science) assessment. Please see the JCQ publication *Instructions for conducting non-examination assessments* for further information.

Any failure by a centre to provide a practical science statement to OCR in a timely manner (by means of an NEA Centre Declaration Form) will be treated as malpractice and/or maladministration [under General Condition A8 (*Malpractice and maladministration*)].

2d. Prior knowledge, learning and progression

- Learners in England who are beginning a GCSE (9–1) course are likely to have followed a Key Stage 3 programme of study.
- There are no prior qualifications required in order for learners to enter for a GCSE (9–1) in Combined Science B (Twenty First Century Science).

- GCSEs (9–1) are qualifications that enable learners to progress to further qualifications either Vocational or General.

There are a number of Science specifications at OCR.

Find out more at www.ocr.org.uk

3 Assessment of GCSE (9–1) in Combined Science B (Twenty First Century Science)

3a. Forms of assessment

The GCSE (9–1) in Combined Science B (Twenty First Century Science) is a linear qualification with 100% external assessment.

OCR's GCSE (9–1) in Combined Science B (Twenty First Century Science) consists of eight examined papers

that are externally assessed. Four are at Foundation Tier and four are at Higher Tier. Each paper has a duration of 1 hour and 45 minutes.

Combined Science Biology (Components 01 and 05)

These papers, one at Foundation Tier and one at Higher Tier, are each worth 95 marks and assess content from across all teaching chapters B1 to B6 and BCP8. Learners answer all the questions.

Question styles include short answer (practical, maths, objective, synoptic, structured) and extended Level of Response questions.

Combined Science Chemistry (Components 02 and 06)

These papers, one at Foundation Tier and one at Higher Tier, are each worth 95 marks and assess content from across all teaching chapters C1 to C6 and BCP8. Learners answer all the questions.

Question styles include short answer (practical, maths, objective, synoptic, structured) and extended Level of Response questions.

Combined Science Physics (Components 03 and 07)

These papers, one at Foundation Tier and one at Higher Tier, are each worth 95 marks and assess content from across all teaching chapters P1 to P6 and BCP8. Learners answer all the questions.

Question styles include short answer (practical, maths, objective, synoptic, structured) and extended Level of Response questions.

Combined Science Combined Science (Components 04 and 08)

These papers, one at Foundation Tier and one at Higher Tier, are each worth 75 marks and assess content from across all teaching chapters. Learners answer all the questions. Question styles include

short answer (practical, maths, objective, synoptic, structured) and extended Level of Response questions.

3b. Assessment objectives (AO)

There are three Assessment Objectives in OCR GCSE (9–1) in Combined Science B (Twenty First Century Science).

These are detailed in the table below.

Assessment Objectives		Weighting (%)	
		Higher	Foundation
AO1	Demonstrate knowledge and understanding of: <ul style="list-style-type: none"> scientific ideas scientific techniques and procedures 	40	40
AO2	Apply knowledge and understanding of: <ul style="list-style-type: none"> scientific ideas scientific enquiry, techniques and procedures 	40	40
AO3	Analyse information and ideas to: <ul style="list-style-type: none"> interpret and evaluate make judgements and draw conclusions develop and improve experimental procedures 	20	20

The Assessment Objectives are further broken down to Assessment Objective elements as shown in the table below.

Assessment Objective elements	
AO1	Demonstrate knowledge and understanding of scientific ideas and scientific techniques and procedures.
AO1.1	Demonstrate knowledge and understanding of scientific ideas.
AO1.2	Demonstrate knowledge and understanding of scientific techniques and procedures.
AO2	Apply knowledge and understanding of scientific ideas and scientific enquiry, techniques and procedures.
AO2.1	Apply knowledge and understanding of scientific ideas.
AO2.2	Apply knowledge and understanding of scientific enquiry, techniques and procedures.
AO3	Analyse information and ideas to interpret and evaluate, make judgements and draw conclusions and develop and improve experimental procedures.
AO3.1	Analyse information and ideas to interpret and evaluate.
AO3.1a	Analyse information and ideas to interpret.
AO3.1b	Analyse information and ideas to evaluate.
AO3.2	Analyse information and ideas to make judgements and draw conclusions.
AO3.2a	Analyse information and ideas to make judgements.

AO3.2b	Analyse information and ideas to draw conclusions.
AO3.3	Analyse information and ideas to develop and improve experimental procedures.
AO3.3a	Analyse information and ideas to develop experimental procedures.
AO3.3b	Analyse information and ideas to improve experimental procedures.

3c. Command words

The key list of common command words used in our exams is listed below. The definitions are intended to provide guidance to teachers and students as to what a student will be expected to do when these words are used in examinations.

The exact response expected to a command word will be dependent on the context. At all times, we advise students to read the full question carefully to be sure of what they are being asked to do.

Command word	Definition
analyse	Separate information into components and identify their characteristics. Discuss the pros and cons of a topic or argument and make reasoned comment.
calculate	Generate a numerical answer, with workings shown.
choose	Select from a list or a number of alternatives.
classify	Assign to a category or group.
compare and contrast	Identify similarities and differences.
complete	Add words, numbers, labels or plots to complete a sentence, table, diagram or graph.
conclude	Make a decision after reasoning something out.
construct	Write out or draw the requested item, e.g. '...Construct a dot and cross diagram for sodium chloride...' or '...Construct a balanced equation for a specific reaction...'
convert	Change a defined item to another defined item, e.g. '...Convert your calculated answer in g to an answer in moles...'
deduce	Use your knowledge and/or supplied data to work something out, e.g. '...Deduce the empirical formula of compound X (using supplied data)...'
define	Use your knowledge to state the meaning of a given term, e.g. '...Define the term specific heat capacity...' or '...Define the term momentum...'
describe	Set out the facts or characteristics. The description of a process should address what happens, and when and/or where it happens. (Compare with 'Explain') For example, when asked to <u>describe</u> the change in rate of reaction seen on a graph, the expected response might be to describe whether the rate of reaction remains constant, or decreases or increases over time.
design	Plan and present ideas to show a layout / function / workings / object / system / process.

Command word	Definition
determine	Obtain a solution by following a set of procedures. Obtain a numerical value by carrying out a series of calculations. Also see 'Find' which is more commonly used for Foundation tier.
discuss	Give an account that addresses a range of ideas and arguments.
draw	Produce a diagram with sufficient detail and labels to illustrate the answer. (Compare with 'Sketch')
estimate	Assign an approximate value.
evaluate	Make a qualitative judgement taking into account different factors and using available knowledge / experience / evidence.
explain	Set out reasons and/or mechanisms to address why and/or how something happens. (Compare with 'Describe') For example, when asked to <u>explain</u> the change in rate of reaction seen on a graph, the expected response would suggest scientific reasons for any change seen, for example in terms of molecular collisions or enzymatic action.
find	Obtain a solution by following a set of procedures. Obtain a numerical value by carrying out a series of calculations. Also see 'Determine'. Find is more commonly used for Foundation tier.
give	A short answer is required without explanation (unless separately requested).
how	In what way?
identify	Recognise, list, name or otherwise characterise.
illustrate	Make clear by using examples or providing diagrams.
justify	Present a reasoned case for actions or decisions made.
label	Add names or other identifying words or symbols to a diagram.
measure	Establish a value using a suitable measuring instrument or technique.
name	Provide appropriate word(s) or term(s).
outline	Provide a description setting out the main characteristics / points.
plan	Consider, set out and communicate what is to be done.
plot	Translate data into a suitable graph or chart, with labelled axes.
predict	Make a judgement of an event or action that will or would happen in the future, as a result of knowledge, experience or evidence.
recall	Use your knowledge of the specification to remember a relevant key fact which needs to be used in the question.
select	Carefully choose as being the most suitable for a task or purpose.
show	Write down details, steps or calculations to prove a fact or answer.
sketch	Produce a simple, freehand drawing to illustrate the general point being conveyed. Detail is not required. (Compare with 'Draw') In the context of a graph, the general shape of the curve would be sufficient without plotting precise points. (Compare with 'Plot')

state or define	Express in precise terms the nature, state or meaning.
suggest	Give possible alternatives, produce an idea, put forward (for example) an idea or a plan for consideration.
use / using	The answer must be based on information given in the question.
what	A request for information, clarified by the context or question in which it is contained.
which	Identify an object, word or explanation.
why	For what reason?
write	Present the required information, e.g. '...Write balanced equations that represent the radioactive decay of...'

AO weightings in OCR GCSE (9–1) in Combined Science B (Twenty First Century Science)

The relationship between the Assessment Objectives and the components are shown in the following table:

Component	% of overall GCSE (9–1) in Combined Science B (Twenty First Century Science) (J260)			
	AO1	AO2	AO3	Total
Biology (Foundation Tier) J260/01	11.94	10.56	3.90	26.4
Chemistry (Foundation Tier) J260/02	11.94	10.56	3.90	26.4
Physics (Foundation Tier) J260/03	11.94	10.56	3.90	26.4
Combined science (Foundation Tier) J260/04	4.18	8.32	8.30	20.8
Total	40	40	20	100
Component	AO1	AO2	AO3	Total
Biology (Higher Tier) J260/05	11.94	10.56	3.90	26.4
Chemistry (Higher Tier) J260/06	11.94	10.56	3.90	26.4
Physics (Higher Tier) J260/07	11.94	10.56	3.90	26.4
Combined science (Higher Tier) J260/08	4.18	8.32	8.30	20.8
Total	40	40	20	100

3d. Tiers

This scheme of assessment consists of two tiers: Foundation Tier and Higher Tier. Foundation Tier assesses grades 5–5 to 1–1 and Higher Tier assesses grades 9–9 to 4–4. An allowed grade 4–3 may be

awarded on the Higher Tier option for learners who are a small number of marks below the grade 4–4 boundary. Learners must be entered for either the Foundation Tier or the Higher Tier.

3e. Assessment availability

There will be one examination series available each year in May/June to **all** learners.

All examined components must be taken in the same examination series at the end of the course.

This specification will be certificated from the June 2018 examination series onwards.

3f. Retaking the qualification

Learners can retake the qualification as many times as they wish.

They retake all components in the tier of entry of the qualification.

3g. Assessment of extended response

Extended response questions which are marked using a level of response mark scheme are included in all externally assessed papers. These are indicated in papers and mark schemes by an asterisk (*).

Extended response questions provide learners with the opportunity to demonstrate their ability to construct and develop a sustained and coherent line of reasoning.

3h. Synoptic assessment

Synoptic assessment tests the learners' understanding of the connections between different elements of the subject.

Synoptic assessment has been defined, for the purposes of this qualification, as allowing learners the opportunity to demonstrate the ability to draw together different areas of knowledge, skills and/or understanding from across the full course of study. The emphasis of synoptic assessment is to encourage the development of the understanding of Combined Science B (Twenty First Century Science) as a discipline. All papers contain an element of synoptic assessment.

Synoptic assessment requires learners to make and use connections within and between different areas of biology, chemistry or physics for example by:

- applying knowledge and understanding of more than one area to a particular situation or context
- using knowledge and understanding or principles and concepts in planning experimental and investigative work and in the analysis and evaluation of data
- bringing together scientific knowledge and understanding from different areas of the subject and applying them.

3i. Calculating qualification results

A learner's overall qualification grade for OCR GCSE (9–1) in Combined Science B (Twenty First Century Science) will be calculated by adding together their marks from the four components taken to give their total weighted mark. This mark will then be

compared to the qualification level grade boundaries for the entry option taken by the learner and for the relevant exam series to determine the learner's overall qualification grade.

4 Admin: what you need to know

The information in this section is designed to give an overview of the processes involved in administering this qualification so that you can speak to your exams officer. All of the following processes require you to submit something to OCR by a specific deadline.

More information about the processes and deadlines involved at each stage of the assessment cycle can be found in the Administration area of the OCR website.

OCR's *Admin overview* is available on the OCR website at <http://www.ocr.org.uk/administration>.

4a. Pre-assessment

Estimated entries

Estimated entries are your best projection of the number of learners who will be entered for a qualification in a particular series. Estimated entries

should be submitted to OCR by the specified deadline. They are free and do not commit your centre in any way.

4

Final entries

Final entries provide OCR with detailed data for each learner, showing each assessment to be taken. It is essential that you use the correct entry code, considering the relevant entry rules.

Final entries must be submitted to OCR by the published deadlines or late entry fees will apply.

All learners taking a GCSE (9–1) in Combined Science B (Twenty First Century Science) must be entered for one of the following entry options:

Entry option		Components		
Entry code	Title	Code	Title	Assessment type
J260 F	Combined Science B (Twenty First Century Science) (Foundation Tier)	01	Biology (Foundation Tier)	External Assessment
		02	Chemistry (Foundation Tier)	External Assessment
		03	Physics (Foundation Tier)	External Assessment
		04	Combined science (Foundation Tier)	External Assessment
J260 H	Combined Science B (Twenty First Century Science) (Higher Tier)	05	Biology (Higher Tier)	External Assessment
		06	Chemistry (Higher Tier)	External Assessment
		07	Physics (Higher Tier)	External Assessment
		08	Combined science (Higher Tier)	External Assessment

4b. Special consideration

Special consideration is a post-assessment adjustment to marks or grades to reflect temporary injury, illness or other indisposition at the time the assessment was taken.

Detailed information about eligibility for special consideration can be found in the JCQ publication *A guide to the special consideration process*.

4c. External assessment arrangements

Regulations governing examination arrangements are contained in the JCQ *Instructions for conducting examinations*.

Learners are permitted to use a scientific or graphical calculator for components 01–08. Calculators are subject to the rules in the document *Instructions for Conducting Examinations* published annually by JCQ (www.jcq.org.uk).

Head of Centre Annual Declaration

The Head of Centre is required to provide a declaration to the JCQ as part of the annual NCN update, conducted in the autumn term, to confirm that the centre is meeting all the requirements detailed in the specification, including that they have provided all candidates with the opportunity to undertake the prescribed practical activities.

Any failure by a centre to provide the Head of Centre Annual Declaration will result in your centre status being suspended and could lead to the withdrawal of our approval for you to operate as a centre.

Private candidates

Private candidates may enter for OCR assessments.

A private candidate is someone who pursues a course of study independently but takes an examination or assessment at an approved examination centre. A private candidate may be a part-time student, someone taking a distance learning course, or someone being tutored privately. They must be based in the UK.

The GCSE Combined Science B (Twenty First Century Science) qualification requires learners to complete sixteen practical activities. These practical activities are an essential part of the course and will allow learners to develop skills for further study or employment as well as imparting important knowledge that is part of the specification.

There is no direct assessment of the practical skills part of the course. However, learners will need to have completed the activities to prepare fully for the written examinations as there will be questions that assess practical skills.

Private candidates need to contact OCR approved centres to establish whether they are prepared to host them as a private candidate. The centre may charge for this facility and OCR recommends that the arrangement is made early in the course.

Further guidance for private candidates may be found on the OCR website: <http://www.ocr.org.uk>.

4d. Results and certificates

Grade Scale

GCSE (9–1) qualifications are graded on the scale: 9–9 to 1–1, where 9–9 is the highest. Grades achievable on the Higher Tier are 9–9 to 4–4 (with an allowed grade 4–3). Grades achievable on the Foundation Tier

are 5–5 to 1–1. Learners who fail to reach the minimum standard of 1–1 will be Unclassified (U). Only subjects in which grades 9–9 to 1–1 are attained will be recorded on certificates.

Results

Results are released to centres and learners for information and to allow any queries to be resolved before certificates are issued.

Centres will have access to the following results information for each learner:

- the grade for the qualification
- the raw mark for each component
- the total weighted mark for the qualification.

The following supporting information will be available:

- raw mark grade boundaries for each component
- weighted mark grade boundaries for each entry option.

Until certificates are issued, results are deemed to be provisional and may be subject to amendment.

A learner's final results will be recorded on an OCR certificate. The qualification title will be shown on the certificate as 'OCR Level 1/Level 2 GCSE (9–1) in Combined Science B (Twenty First Century Science)'.

4e. Post-results services

A number of post-results services are available:

- **Enquiries about results** – If you are not happy with the outcome of a learner's results, centres may submit an enquiry about results.
- **Missing and incomplete results** – This service should be used if an individual subject result

for a learner is missing, or the learner has been omitted entirely from the results supplied.

- **Access to scripts** – Centres can request access to marked scripts.

4f. Malpractice

Any breach of the regulations for the conduct of examinations and non-exam assessment may constitute malpractice (which includes maladministration) and must be reported to OCR as

soon as it is detected. Detailed information on malpractice can be found in the JCQ publication *Suspected Malpractice in Examinations and Assessments: Policies and Procedures*.

5 Appendices

5a. Grade descriptors

Grade descriptors for GCSE (9–1) single science (biology, chemistry and physics) and combined science:

1. Grades 8 and 8–8

1.1 To achieve Grades 8 and 8–8 candidates will be able to:

- demonstrate relevant and comprehensive knowledge and understanding and apply these correctly to both familiar and unfamiliar contexts using accurate scientific terminology
- use a range of mathematical skills to perform complex scientific calculations
- critically analyse qualitative and quantitative data to draw logical, well-evidenced conclusions
- critically evaluate and refine methodologies, and judge the validity of scientific conclusions.

2. Grades 5 and 5–5

2.1 To achieve Grades 5 and 5–5 candidates will be able to:

- demonstrate mostly accurate and appropriate knowledge and understanding and apply these mostly correctly to familiar and unfamiliar contexts, using mostly accurate scientific terminology
- use appropriate mathematical skills to perform multi-step calculations
- analyse qualitative and quantitative data to draw plausible conclusions supported by some evidence
- evaluate methodologies to suggest improvements to experimental methods, and comment on scientific conclusions.

3. Grades 2 and 2–2

3.1 To achieve Grades 2 and 2–2 candidates will be able to:

- demonstrate some relevant scientific knowledge and understanding using limited scientific terminology
- perform basic calculations
- draw simple conclusions from qualitative or quantitative data
- make basic comments relating to experimental method.

5b. Overlap with other qualifications

There is a small degree of overlap between the content of this specification and those for GCSE (9–1) in Biology B (Twenty First Century Science), GCSE (9–1) in Chemistry B and GCSE (9–1) in Physics B

courses. The links between the specifications may allow for some co-teaching, particularly in the area of working scientifically.

5c. Accessibility

Reasonable adjustments and access arrangements allow learners with special educational needs, disabilities or temporary injuries to access the assessment and show what they know and can do, without changing the demands of the assessment. Applications for these should be made before the examination series. Detailed information about eligibility for access arrangements

can be found in the JCQ *Access Arrangements and Reasonable Adjustments*.

The GCSE (9–1) qualification and subject criteria have been reviewed in order to identify any feature which could disadvantage learners who share a protected Characteristic as defined by the Equality Act 2010. All reasonable steps have been taken to minimise any such disadvantage.

5d. Units in science

It is expected that learners will show understanding of the SI base units and derived units listed below.

They will be able to use them in qualitative work and calculations. These units and their associated quantities are dimensionally independent.

SI base units		
Physical quantity	Unit	Unit
Length	Metre	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Current	Ampere	A
Amount of a substance	mole	mol

SI derived units		
Physical quantity	Unit(s)	Unit(s)
Area	squared metre	m ²
Volume	cubic metre; litre; cubic decimetre	m ³ ; l; dm ³
Density	kilogram per cubic metre	kg/m ³
Temperature	degree Celsius	°C
Pressure	Pascal	Pa
Specific heat capacity	joule per kilogram per degree Celsius	J/kg°C
Specific latent heat	joule per kilogram	J/kg
Speed	metre per second	m/s
Force	Newton	N
Gravitational field strength	newton per kilogram	N/kg
Acceleration	metre per squared second	m/s ²
Frequency	hertz	Hz
Energy	joule	J
Power	watt	W
Electric charge	coulomb	C
Electric potential difference	volt	V
Electric resistance	ohm	Ω
Magnetic flux density	tesla	T

5e. Mathematical skills

The mathematical skills required for the GCSE (9–1) in biology (B), chemistry (C), physics (P)

and combined science (CS) are shown in the table below.

	Mathematical skills	Subject			
M1	Arithmetic and numerical computation				
a	Recognise and use expressions in decimal form	B	C	P	CS
b	Recognise and use expressions in standard form	B	C	P	CS
c	Use ratios, fractions and percentages	B	C	P	CS
d	Make estimates of the results of simple calculations	B	C	P	CS
M2	Handling data				
a	Use an appropriate number of significant figures	B	C	P	CS
b	Find arithmetic means	B	C	P	CS
c	Construct and interpret frequency tables and diagrams, bar charts and histograms	B	C	P	CS
d	Understand the principles of sampling as applied to scientific data	B			CS
e	Understand simple probability	B			CS
f	Understand the terms mean, mode and median	B		P	CS
g	Use a scatter diagram to identify a correlation between two variables	B		P	CS
h	Make order of magnitude calculations	B	C	P	CS
M3	Algebra				
a	Understand and use the symbols: =, <, <<, >>, >, ∞, ~	B	C	P	CS
b	Change the subject of an equation		C	P	CS
c	Substitute numerical values into algebraic equations using appropriate units for physical quantities		C	P	CS
d	Solve simple algebraic equations	B		P	CS
M4	Graphs				
a	Translate information between graphical and numeric form	B	C	P	CS
b	Understand that $y=mx+c$ represents a linear relationship	B	C	P	CS
c	Plot two variables from experimental or other data	B	C	P	CS
d	Determine the slope and intercept of a linear graph	B	C	P	CS
e	Draw and use the slope of a tangent to a curve as a measure of rate of change		C	P	CS
f	Understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate			P	CS
M5	Geometry and trigonometry				
a	Use angular measures in degrees			P	CS
b	Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects		C	P	CS
c	Calculate areas of triangles and rectangles, surface areas and volumes of cubes.	B	C	P	CS

5f. Mathematical skills requirement

In order to be able to develop their skills, knowledge and understanding in GCSE (9–1) Combined Science B (Twenty First Century Science), learners need to have been taught, and to have acquired competence in, the appropriate areas of mathematics relevant to the subject as indicated in the table of coverage below.

The questions and tasks used to target mathematical skills will be at a level of demand that is appropriate to GCSE (9–1) Combined Science.

In the Foundation Tier question papers, the questions that assess mathematical skills will not be of a lower demand than that which is expected of learners at Key Stage 3, as outlined in the Department for Education's document "Mathematics programme of study: key stage 3".

In the Higher Tier question papers, the questions that assess mathematical skills will not be lower demand than that of questions and tasks in the assessment for the Foundation Tier in a GCSE qualification in Mathematics.

The assessment of quantitative skills would include at least 20% GCSE (or above) mathematical skills at the appropriate tier for combined science.

These skills will be applied in the context of the relevant combined science.

This list of examples is not exhaustive and is not limited to GCSE examples. These skills could be developed in other areas of specification content from those indicated.

	Mathematical skills	Specification reference
M1	Arithmetic and numerical computation	
a	Recognise and use expressions in decimal form	B3.1.7a, B3.2.8a, B3.2.8b, B4.1.5b, C1.1.11, C1.2.5, C1.2.6, C2.1.7, C2.3.7, C5.2.7, C5.2.8, C6.2.9, P1.3.6, P4.2.1, P4.2.7, P4.4.2, P4.4.3, P4.4.4, P4.4.5, P4.4.9, P6.1.2, P6.1.5a, P6.1.6, P6.1.8
b	Recognise and use expressions in standard form	B4.2.2c, C4.3.7, C5.2.9, P5.1.9, P3.5.3, P6.1.2, P6.3.3a
c	Use ratios, fractions and percentages	B1.2.4, B3.1.7a, B3.2.8a, B3.2.8b, B3.2.8d, B3.3.9, B3.4.3b, B4.1.5b, B5.1.8, C1.1.11, C1.2.5, C1.2.6, C3.4.7, C4.3.8, C5.2.7, C5.2.8, C6.2.9, C6.2.12, P1.3.6, P2.1.8, P3.1.2, P3.1.4a, P3.2.1, P3.2.4, P3.3.2, P3.3.3, P3.3.4, P3.3.5, P3.5.3, P4.1.7, P4.2.1, P4.2.4, P4.2.6a, P4.2.7, P4.3.4, P4.3.5, P4.3.9, P4.4.5, P4.4.6, P5.1.9, P5.1.11, P5.1.12, P6.1.1, P6.1.2, P6.1.5a, P6.1.6, P6.1.8, P6.3.5, P6.3.7
d	Make estimates of the results of simple calculations	B4.2.2b, C1.2.5, C1.2.6, C2.1.4, C2.1.6, C4.3.6b, C5.2.8
M2	Handling data	
a	Use an appropriate number of significant figures	B4.2.2a, C5.2.5, P4.2.4, P6.1.8, IaS2.6
b	Find arithmetic means	B3.1.3b, B3.4.3a, C6.2.10, P4.2.2, IaS2.8

	Mathematical skills	Specification reference
c	Construct and interpret frequency tables and diagrams, bar charts and histograms	B3.1.7d, B3.4.3d, B5.4.2a, B6.3.3, C1.3.5, P2.2.3, P2.2.7, P4.3.12, laS2.4, laS2.7
d	Understand the principles of sampling as applied to scientific data	B2.4.3c, B3.4.2
e	Understand simple probability	B1.2.5
f	Understand the terms mean, mode and median	B3.1.3b, B3.4.3a, P4.2.2, P6.3.3a, laS2.8
g	Use a scatter diagram to identify a correlation between two variables	B2.4.3d, P5.1.12, laS2.8, laS3.1
h	Make order of magnitude calculations	B4.2.2a, C1.3.6, P4.2.11, P4.2.10
M3	Algebra	
a	Understand and use the symbols: =, <, <<, >>, >, ∞ , \sim	No direct specification references but statements assessed
b	Change the subject of an equation	
c	Substitute numerical values into algebraic equations using appropriate units for physical quantities	C5.1.5, C5.2.5, C5.2.10, C5.3.1, C5.3.2, P1.3.6, P2.1.3, P3.1.2, P3.1.4a, P3.2.1, P3.2.4, P3.3.2, P3.3.3, P3.3.4, P3.3.5, P3.5.3, P4.1.7, P4.2.1, P4.2.4, P4.2.6a, P4.2.7, P4.3.4, P4.3.5, P4.3.9, P4.4.2, P4.4.3, P4.4.4, P4.4.5, P4.4.6, P4.4.9, P5.1.9, P6.1.2, P6.1.8, P6.3.5, P6.3.7
d	Solve simple algebraic equations	B3.1.3b, P1.3.6, P2.1.3, P3.1.2, P3.1.4a, P3.2.1, P3.2.4, P3.3.2, P3.3.5, P3.5.3, P4.1.7, P4.2.1, P4.2.6a, P4.2.7, P4.3.4, P4.3.5, P4.3.9, P4.4.2, P4.4.3, P4.4.4, P4.4.9, P5.1.11, P6.1.5a, P6.1.6, P6.1.8, P6.3.7
M4	Graphs	
a	Translate information between graphical and numeric form	B2.4.3a, B2.4.3b, B3.1.3b, B3.1.7b, B3.1.7c, B3.2.8c, B3.4.3c, B5.4.2b, B6.3.3, C1.3.5, C2.3.12, C3.4.13, C6.2.8, P2.1.9, P4.2.9, P4.2.10, P4.3.3, P5.1.12, laS2.4, laS2.7
b	Understand that $y=mx+c$ represents a linear relationship	B3.1.3b, B3.2.8c, C6.2.8, C6.2.10, C6.2.11, P4.2.9, P4.2.10, laS2.8
c	Plot two variables from experimental or other data	B2.4.3b, B3.1.3b, B3.1.7c, B3.2.8c, B3.4.3c, C6.2.10, P3.1.6a, P4.2.9, P4.2.10, P5.1.12, laS2.7
d	Determine the slope and intercept of a linear graph	B3.2.8c, C6.2.11, P3.1.6a, P4.2.9, P4.2.10, laS2.8
e	Draw and use the slope of a tangent to a curve as a measure of rate of change	C6.2.11, laS2.8
f	Understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate	P4.2.10, P6.3.6a, laS2.8

	Mathematical skills	Specification reference
M5	Geometry and trigonometry	
a	Use angular measures in degrees	P4.3.3
b	Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects	C2.3.12, C3.4.11, C4.2.7, P4.3.3
c	Calculate areas of triangles and rectangles, surface areas and volumes of cubes.	B2.5.2, B5.1.8, C4.3.9, P6.1.1

5g. The Periodic Table of elements

(1)	(2)											(3)	(4)	(5)	(6)	(7)	(0)
1	2											13	14	15	16	17	18
1 H hydrogen 1.0																	2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
3	4	5	6	7	8	9	10	11	12								
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89–103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium		114 Fl flerovium		116 Lv livermorium		

Key		
atomic number	Symbol	name
relative atomic mass		

5h. Equations in physics

Equations required for Higher Tier only are in bold.

- (a) In solving quantitative problems, learners should be able correctly to recall, and apply the following relationships, using standard S.I. units:

$$\text{force} = \text{mass} \times \text{acceleration} \text{ (P4.3.9)}$$

$$\text{kinetic energy} = 0.5 \times \text{mass} \times (\text{speed})^2 \text{ (P4.4.3)}$$

$$\textbf{momentum} = \textbf{mass} \times \textbf{velocity} \text{ (P4.3.4)}$$

$$\text{work done} = \text{force} \times \text{distance (along the line of action of the force)} \text{ (P4.4.2)}$$

$$\text{power} = \text{energy transferred} \div \text{time (P3.3.2)} \text{ (P4.4.9)}$$

$$\text{efficiency} = \text{useful energy transferred} \div \text{total energy transferred} \text{ (P2.1.8)}$$

$$\text{weight} = \text{mass} \times \text{gravitational field strength} \text{ (P4.1.7)}$$

$$\text{In a gravity field: gravitational potential energy} = \text{mass} \times \text{gravitational field strength} \times \text{height} \text{ (P4.4.4)}$$

$$\text{force exerted by a spring} = \text{extension} \times \text{spring constant} \text{ (P6.3.5)}$$

$$\text{average speed} = \text{distance} \div \text{time} \text{ (P4.2.1)}$$

$$\text{acceleration} = \text{change in speed} \div \text{time taken} \text{ (P4.2.6a)}$$

$$\text{wave speed} = \text{frequency} \times \text{wavelength} \text{ (P1.3.6)}$$

$$\text{charge} = \text{current} \times \text{time} \text{ (P3.1.2)}$$

$$\text{potential difference} = \text{current} \times \text{resistance} \text{ (P3.1.4a)}$$

$$\text{power} = \text{potential difference} \times \text{current} = (\text{current})^2 \times \text{resistance} \text{ (P3.3.4a and b)}$$

$$\text{energy transferred (work done)} = \text{power} \times \text{time} = \text{charge flow} \times \text{potential difference} \text{ (P2.1.3, P3.3.3)}$$

$$\text{density} = \text{mass} \div \text{volume} \text{ (P6.1.2)}$$

$$\text{potential difference} = \text{work done (energy transferred)} \div \text{charge} \text{ (P3.2.1)}$$

- (b) In addition, learners should be able correctly to select from a list and apply the following relationships:

$$(\text{final speed})^2 - (\text{initial speed})^2 = 2 \times \text{acceleration} \times \text{distance} \text{ (P4.2.7)}$$

$$\text{change in internal energy} = \text{mass} \times \text{specific heat capacity} \times \text{change in temperature} \text{ (P6.1.5a)}$$

$$\text{energy to cause a change of state} = \text{mass} \times \text{specific latent heat} \text{ (P6.1.6)}$$

$$\text{energy stored in a stretched spring} = \frac{1}{2} \times \text{spring constant} \times (\text{extension})^2 \text{ (P6.3.7)}$$

$$\textbf{force} = \textbf{magnetic flux density} \times \textbf{current} \times \textbf{length of conductor} \text{ (P3.5.3)}$$

$$\text{potential difference across primary coil} \times \text{current in primary coil} = \text{potential difference across secondary coil} \times \text{current in secondary coil} \text{ (P3.3.5)}$$

$$\textbf{change in momentum} = \textbf{resultant force} \times \textbf{time for which it acts} \text{ (P4.3.5)}$$

5i. Health and safety

In UK law, health and safety is primarily the responsibility of the employer. In a school or college the employer could be a local education authority, the governing body or board of trustees. Employees (teachers/lecturers, technicians etc.), have a legal duty to cooperate with their employer on health and safety matters. Various regulations, but especially the COSHH Regulations 2002 (as amended) and the Management of Health and Safety at Work Regulations 1999, require that before any activity involving a hazardous procedure or harmful microorganisms is carried out, or hazardous chemicals are used or made, the employer must carry out a risk assessment. A useful summary of the requirements for risk assessment in school or college science can be found at <https://www.ase.org.uk>

5

For members, the CLEAPSS® guide, *PS90, Making and recording risk assessments in school science*¹ offers appropriate advice.

Most education employers have adopted nationally available publications as the basis for their Model Risk Assessments.

Where an employer has adopted model risk assessments an individual school or college then

has to review them, to see if there is a need to modify or adapt them in some way to suit the particular conditions of the establishment.

Such adaptations might include a reduced scale of working, deciding that the fume cupboard provision was inadequate or the skills of the learners were insufficient to attempt particular activities safely. The significant findings of such risk assessment should then be recorded in a '*point of use text*', for example on schemes of work, published teachers guides, work sheets, etc. There is no specific legal requirement that detailed risk assessment forms should be completed for each practical activity, although a minority of employers may require this.

Where project work or investigations, sometimes linked to work-related activities, are included in specifications this may well lead to the use of novel procedures, chemicals or microorganisms, which are not covered by the employer's model risk assessments. The employer should have given guidance on how to proceed in such cases. Often, for members, it will involve contacting CLEAPSS®.

¹ These, and other CLEAPSS® publications, are on the CLEAPSS® Science Publications website www.cleapss.org.uk. Note that CLEAPSS® publications are only available to members. For more information about CLEAPSS® go to www.cleapss.org.uk.

Summary of updates

Date	Version	Section	Title of section	Change
December 2017	2	Multiple		Changes to generic wording and OCR website links throughout the specification. No changes have been made to any assessment requirements.
April 2018	2.1	i) Front cover ii) 4d	i) Disclaimer ii) Results and certificates: Results	i) Addition of Disclaimer ii) Amend to Certification Titling
May 2018	2.2	2c and 4c	Practical Science Statement and Head of Centre Annual Declaration	Update in line with new NEA Centre Declaration form.
October 2018	3	3b	Assessment Objectives (AO)	Addition of Assessment Objective elements
December 2018	3.1	i) 2c ii) 3c	i) Content of chapters B1 to BCP8 ii) Command words	i) P3.1 What determines the current in an electric circuit? Assessable learning outcome 7 updated for clarification. ii) Command words
February 2019	3.2	Chapter 5C	Chemical analysis	Definition of mole



YOUR CHECKLIST

Our aim is to provide you with all the information and support you need to deliver our specifications.

- ☐ Bookmark ocr.org.uk/gcsec21combinedscience for all the latest resources, information and news on GCSE (9–1) Twenty First Century Science Combined Science B
 - ☐ Be among the first to hear about support materials and resources as they become available – register for Twenty First Century Science Combined Science B updates at ocr.org.uk/updates
 - ☐ Find out about our professional development at cpdhub.ocr.org.uk
 - ☐ View our range of skills guides for use across subjects and qualifications at ocr.org.uk/skillsguides
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 - ☐ Learn more about Active Results at ocr.org.uk/activeresults
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Download high-quality, exciting and innovative GCSE (9–1) Twenty First Century Science Combined Science B resources from ocr.org.uk/gcsec21combinedscience

Resources and support for our GCSE (9–1) Twenty First Century Science Combined Science B qualification, developed through collaboration between our Science Subject Advisors, teachers and other subject experts, are available from our website. You can also contact our Science Subject Advisors who can give you specialist advice, guidance and support.

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