Guidelines for the content of Key Stage 4 qualifications

This document has been produced by SCORE to help awarding organisations to develop specifications and assessments in the sciences that are challenging, useful, appropriate and engaging.

The document may also be helpful to others seeking advice on curriculum planning in secondary science.

17 June 2013
Guidelines for the content of KS4 qualifications

1. Introduction ........................................................................................................................................... 3
2. Choosing content in the specifications ................................................................................................. 3
3. Assessment .............................................................................................................................................. 4
4. Thinking and working scientifically ...................................................................................................... 5
   4.1. The characteristics of good science .............................................................................................. 5
   4.2. Practical work ............................................................................................................................... 6
   4.3. Mathematical techniques ............................................................................................................... 7
5. Biology content and ideas ...................................................................................................................... 8
   5.1. Big ideas in biology ..................................................................................................................... 8
   5.2. The endeavour of biology ........................................................................................................... 10
   5.3. Practical biology ......................................................................................................................... 10
6. Chemistry content and ideas ................................................................................................................ 11
   6.1. Big Ideas in chemistry .................................................................................................................. 11
   6.2. The endeavour of chemistry ....................................................................................................... 13
   6.3. Practical chemistry ...................................................................................................................... 13
7. Physics content and ideas ..................................................................................................................... 14
   7.1. Big ideas in physics ...................................................................................................................... 14
   7.2. The endeavour of physics (thinking like a physicist) ................................................................. 16
   7.3. Practical physics .......................................................................................................................... 17
8. Earth Science ........................................................................................................................................... 17
   8.1. Big ideas in Earth Science ........................................................................................................... 17
1. Introduction

This document has been produced by SCORE (a collaboration of five leading science organisations working together on science education policy: Association for Science Education, Institute of Physics, Royal Society, Royal Society of Chemistry and Society of Biology). The document’s main purpose is to help awarding organisations to develop specifications and assessments in the sciences that are challenging, useful, appropriate and engaging. The document describes some principles for selecting and sequencing content and, in particular, some guidance on the incorporation of practical work and mathematical techniques.

The document may also be helpful to others seeking advice on curriculum planning in secondary science.

2. Choosing content in the specifications

Scientific understanding is fundamental to human culture. The sciences are powerful: they provide solutions to complex social and environmental challenges and improve human health and wellbeing. The sciences justify their position in the core curriculum by illustrating this power and developing scientific understanding – contributions that are vital for engaging fully in modern life. They also provide and illustrate ways of thinking that are useful in their own right and an important part of the intellectual development of young people. Specifications at Key Stage 4 should reflect and engender these contributions.

The main principles for developing specifications, their content and its assessment are listed below. Qualifications in the sciences should be:

- **Preparatory.** Provide a sound basis for careers involving the sciences. It should also provide those who do not take science beyond the age of 16 with a good grounding in the methods and ideas of science.
- **Distinct but interdisciplinary.** Ideas within and across the disciplines are interlinked and part of a consistent and coherent interpretation of the world. SCORE would expect science disciplines to normally be taught as separate subjects by specialist teachers, leading either to qualifications in the three disciplines or to a combined science qualification.
- **Unapologetic.** The specifications should exemplify the power of the sciences whilst also showing that there are limits to what we know and that there are areas of human activity that lie outside the bounds of science.
- **From the domains of biology, chemistry and physics.** In sections 5 to 7, we have outlined an overview of the core knowledge and understanding of each discipline. These sections do not define content but rather the areas of ideas from which content should be taken. Section 8 outlines the big ideas for Earth Science, which draws on approaches and content from the other three sciences.
• **Rich.** The content should be rich – allowing for a deep understanding of its ideas so students are able to apply their knowledge in other contexts.

• **Comprised of content that earns its place.** Any statement of content should earn its place - it should do one or more of the following:
  o address one or more of the big ideas within the discipline – see the first part within each of sections 5 to 7.
  o provide opportunities to experience what it means to think scientifically– see the second part within each of sections 5 to 7; these parts cover the ways of thinking within a discipline. These ways of thinking are challenging, transferrable and intellectually valuable.
  o provide opportunities for worthwhile practical work – see section 4.2. Not only should the content and ideas of the sciences be developed through the judicious use of practical work, the practical work should develop techniques and procedural knowledge that is applicable to carrying out tasks and solving problems in and beyond the sciences.
  o employ knowledge from the mathematics curriculum in a coherent way – see section 4.3.
  o allow for the development of ideas within a range of contexts, including future, current and historical.

• **Part of the whole picture.** Within a specification, the content should be chosen to allow for effective sequencing as part of a whole, building on prior knowledge and developing understanding to enable further study.

3. **Assessment**

Assessment should reinforce the character and ethos of a subject. Examinations in the sciences should assess the subject-specific capabilities of candidates, their understanding and their knowledge, and should also assess the nature, processes and methods of science. Assessment items should be subtle and probing to engender high quality teaching and measure high quality learning. Below we have set out our guiding principles for assessment.

- Assessment driven by the learning outcomes. Definitions of what students will be expected to know and do lead to considerations of how these learning outcomes should be taught and assessed¹.
- Practical work is intrinsic to the teaching and learning of the sciences and this must be reflected in assessment.
- There should be an emphasis on demonstrating understanding.

¹ The University of York is currently undertaking research into this approach. The project, led by Robin Millar and Mary Whitehouse, titled *The York Science Project – embedding assessment for learning* - http://www.york.ac.uk/media/educationalstudies/documents/curriculumprojects/YS%20in%20EiSxtra1.pdf
There should be opportunities for students to demonstrate the depth of their understanding of scientific concepts and application of mathematical knowledge within the sciences.

4. Thinking and working scientifically

This section covers all three sciences. It outlines ways in which the sciences and scientists work and how scientific ideas and theories have been developed and established. Students should gain an insight into the working methods of the sciences through authentic experiences in the classroom and laboratory.

To understand the strength of the claims within the sciences, it is crucial to appreciate the processes, evidence and reasoning on which those claims are based. Gathering and interpreting evidence are at the heart of the sciences and should be a part of the sciences at school. The Royal Society's motto *nullius in verba*, which translates ‘take nobody’s word for it’, is a reminder that we should be encouraging young learners to understand the significance of evidence, not bald facts or opinions in science. Any assessment should encourage this way of thinking.

4.1. The characteristics of good science

The sciences should allow students to gain an authentic view of what it is like to study and work in the sciences (including thinking like a scientist). Students should be familiar with ideas about the scientific method - a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge based on empirical evidence and peer review. The sciences are an important part of students’ cultural inheritance, whether or not they go on to work in the sciences.

Specifically, their learning should engender an understanding that the sciences are characterised by the following:

- **Evidence** – acquiring evidence is essential, as is the ability to undertake evidence-based thinking and logical reasoning;
- **Experiments** – scientific experiments and investigations are key to the clarification and consolidation of theories.
- **Measurement** – the sciences are about observing and measuring phenomena to make predictions to test theories;
- **Prediction** – using established models and laws to make predictions or creating new explanations in real world situations,
- **Construction** – using established laws to make things we know will work;
- **Explanation** – to get closer to a full understanding.
- **Repeatability, reproducibility and validity** and falsification – scientific claims are replicable and should be testable; it is important to understand why a particular interpretation of evidence may be inconsistent.
4.2. Practical work

Practical work sits within thinking and working scientifically and is intrinsic to science teaching and learning. At the end of Key Stage 4, through practical work, students should develop understanding and appreciation for ‘how we know’, ‘how we find out’ as well as ‘what we know’. Students should experience a wide range of practical work activities to develop and enhance the following sets of skills and knowledge:

**Technical and manipulative skills**

Students should develop a range of skills associated with using apparatus and materials with due regard for safety and purpose, in the laboratory and the field. For example:

- Assembling and using apparatus safely, with or without instructions; identifying and rectifying faults
- Making and recording observations using a range of appropriate equipment and techniques; use apparatus to make a series of observations, including over time, by manipulating apparatus
- Using a range of instruments, sensors and techniques, take and record readings and make measurements, taking into account appropriate uncertainty and precision
- Using a variety of standard scientific practical techniques (specified under the subject-specific sections)

**Carrying out scientific procedures**

Students should develop the knowledge of different scientific procedures that will enable them to do the following steps (both independently and as a complete investigation):

- Plan and design investigations and experiments, both for single variables and for more complex situations; selecting appropriate methods, identifying the appropriate variables to be manipulated or held constant; identifying hazards and minimising risk
- Collect, estimate and determine data, using the techniques outlined above
- Present observations and data meaningfully using tables, charts, drawings and diagrams, following current scientific conventions
- Analyse and interpret observations and data, using calculations and scientific models where appropriate
- Present reasoned explanations with due regard for the quality of the evidence

**Knowledge and understanding of scientific concepts**

Practical work should also be included in the teaching of science to provide experiences on which students can build their understanding of scientific concepts. It is important that teachers select appropriate activities that build on existing understanding, or challenge students thinking.
4.2.1. Assessment of practical work

Knowledge and understanding of scientific concepts can be assessed through written examination, while technical and manipulative skills can best be assessed through direct observation by the assessor. Assessing the way in which scientific procedures are carried out may need a combination of the two.

4.3. Mathematical techniques

Mathematics is integral to the sciences, allowing students to capture, understand and describe many scientific phenomena. It is a quantitative tool for understanding scientific ideas. SCORE is keen to work with awarding organisations over the development of mathematical assessment that encourages an authentic experience of the sciences. The mathematical requirements in science Key Stage 4 should be coherent with mathematics Key Stage 4 assessment.

The following are the minimum mathematical requirements for biology, chemistry and physics.

- Arithmetic and numerical computation
  - Recognise and use expressions in decimal form.
  - Recognise expressions in standard form.
  - Use ratios, fractions and percentages
  - Make estimates of the results of simple calculations, without using a calculator
  - Use calculators to handle \( \sin x, \cos x, \tan x \) where \( x \) is expressed in degrees

- Handling data
  - Use an appropriate number of significant figures
  - Find arithmetic means
  - Construct and interpret frequency tables and diagrams, bar charts and histograms
  - Understand the principles of sampling as applied to scientific data
  - Understand simple probability
  - Understand the terms mean, mode and median
  - Use a scatter diagram to identify a correlation between two variables
  - Make order of magnitude calculations

- Algebra
  - Understand and use the symbols: \( =, <, <<, >>, >, \propto, \sim \)
  - Change the subject of an equation
  - Substitute numerical values into algebraic equations using appropriate units for physical quantities
  - Solve simple algebraic equations

- Graphs
  - Translate information between graphical and numeric form
Understand that \( y=mx+c \) represents a linear relationship
- Plot two variables from experimental or other data
- Determine the slope and intercept of a linear graph
- Draw and use the slope of a tangent to a curve as a measure of rate of change
- Understand the physical significance of area between a curve and the \( x \)-axis and measure it by counting squares as appropriate

- Geometry and trigonometry
  - Appreciate angles
  - Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects
  - Calculate areas of triangles and rectangles, surface areas and volumes of cubes.

5. Biology content and ideas

Biology is the study of life and living things including animals, plants and micro-organisms, their relationships to each other and the natural environment. The study of biology involves collecting and interpreting information about the natural world in order to identify patterns and relate cause and effect. Biological information is used to help humans improve their own lives and create a sustainable world for future generations.

5.1. Big ideas in biology

The following big ideas reflect what a successful biology student should know at the age of 16. They are presented as headline themes, across which there are many connections and links to other sciences. These big ideas, and their content, will require different levels of detail and weighting within the biology curriculum. We have included some indicative content to highlight the richness of the ideas and themes presented, but the content is not intended to indicate sequencing.

All school children should have the opportunity to gain understanding of, and confidence in, these ideas during their biology education. Each stage should build towards a deep understanding of these big ideas and this should be reflected in a coherent and integrated biology curriculum in schools.

- **Interdependence and interactions.** *Living organisms interact with each other and the environment in complex and dynamic systems.*
  - Living organisms exist as individuals and together form populations of single species, communities of many species and ecosystems, interacting with each other and the non-living environment;
  - Living organisms are interdependent and show adaptations to their environment;
  - Living organisms interact and communicate within and between species using a variety of mechanisms;
The responses of living organisms to their environment and one another create feedback that affects them and/or their environment;

- Ecosystems provide resources and processes that are beneficial to humans;
- Interactions between living organisms (of the same and other species), their environment and humans can affect the viability of individuals, populations and communities in a variety of ways.

**Material cycles and energy.** All living organisms use energy resources to carry out chemical reactions that are essential to life.

- Life on Earth is dependent on trapping and transferring energy from the environment; the Sun is the source of energy for photosynthesis in which green plants and algae fix carbon dioxide and combine it with hydrogen from water to make organic compounds;
- Energy is stored in chemical systems in living organisms; 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.

**Evolution.** Populations of organisms change over time as they acquire characteristics gained through genome mutations that make some individual organisms better suited to survival and reproduction, and more likely to pass on these characteristics to their offspring. This process leads to evolution.

- Genes are made of DNA and code for the molecules that control the chemical reactions in cells, and form the physical structures of cells and extracellular material;
- Offspring inherit genetic material from their parents;
- The characteristics of a living organism are determined by its genome, proteins and the interaction of these with its environment;
- Genome mutations generate genetic variation which can lead to phenotypic variation within species;
- Evolution accounts for biodiversity and how organisms are all related to varying degrees.
- Natural selection is the result of competition for survival and reproduction between genetically different individuals in populations and results in evolution.

**Structure and Function.** Living organisms consist of highly adapted structures that reflect their evolutionary adaptation towards better fitness for their functions.

- Life processes depend on molecules whose function is related to their structure;
- The fundamental units of living organisms are cells;
- Development involves the growth, differentiation and specialisation of cells and occurs in different phases throughout an organism's life cycle;
Organ systems consist of highly adapted structures (cells, tissues, organs) which enable living processes and functions to be performed in effective ways;
Factors that affect the structure and function of biological structures can have an impact on the health and wellbeing of living organisms.

5.2. The endeavour of biology

Biology deals with complex systems which are predictable to varying degrees. Biologists use a range of approaches to analyse complex systems:

- **Sampling:** biologists cannot observe and measure everything; therefore, they have to rely on samples to represent whole populations and communities;

- **Complexity / uncertainty:** biologists deal with complex living systems where it is not always possible to predict the outcomes of interventions and change over time; it is therefore not always possible to reproduce the conditions of biological experiments reliably or isolate all controlled variables;

- **Statistical analysis and using data sets:** biologists apply statistical techniques to ascertain their level of confidence in data obtained in experiments where not all variables can be controlled. Biologists often deal with large data sets generated from multiple experiments; this is not always reproducible in a classroom environment though is critical in understanding how much research in biology proceeds;

- **Modelling:** these models may be *in silico*, statistical, or may be ‘model’ organisms used to assist in developing biological theories and explanations of complex systems;

- **Ethical considerations:** the acquisition and application of biological knowledge and techniques requires sensitivity to societal, economic and environmental impacts.

5.3. Practical biology

By the age of 16 we would expect that every student has had opportunities to directly experience, and be confident working with, a range of methods, procedures and techniques. These opportunities will include developing skills and using them as part of experiments and investigations which will challenge and enhance their understanding of scientific concepts and processes. As a minimum they should have experienced and be confident working with the examples below:

- **Studying, classifying and identifying:** organisms within and from a range of habitats; investigating and comparing their behaviour, physiology, environmental responses, and population patterns/dynamics; to include use of appropriate sampling, observation and measurement equipment such as keys, quadrats and transects, and heart rate monitors.

- **Microscopy and histology:** of organisms, tissues and cells; to include the preparation of specimens and slides; use of appropriate magnification and
manipulation under a light microscope to accurately record and interpret observations.

- **Biochemical analysis and investigation**: of a range of biological molecules; to include enzyme reactions, photosynthesis and respiration, food tests, and fermentation – and involving preparing a series of dilutions, accurately measuring the amount of product over time, and safe use of water baths.

- **Growth and culture**: of organisms, particularly plants and microorganisms; to include the use of aseptic technique, investigations of variables on germination and growth rates, and safe use of an autoclave.

- **Handling living and preserved material**: to observe organisms’ internal and external structures and to gain an understanding of their function. This should include dissection of an organism, or parts of an organism, using a scalpel (this may include animal or plant tissue).

6. Chemistry content and ideas

Chemistry is the science of the composition, structure, properties and reactions of matter. The science of chemistry can be described in terms of core concepts, e.g. atoms and atomic structure, as detailed below. However, chemistry is a practical science, and we would expect students to appreciate that chemistry is not just about abstract concepts; it is also about making (synthesis), measuring (analysis) and identification (characterisation).

Chemistry enables us to understand the world around us, and provides solutions to challenges we need to address in the 21st century, e.g. health, food, water and future energy resources.

During KS4, we expect students to study the fundamental chemistry concepts, and to explore modern and sometimes historical contexts which are locally and globally relevant. This is illustrated in detail in the RSC Global Framework for Education 14-16 Age Range.

6.1. Big Ideas in chemistry

Below outlines the core concepts of chemistry and the application of this knowledge to the endeavour of chemistry (synthesis, analysis and characterisation).

- **States of matter**: Matter can exist in different states; solid, liquid or gas, at different temperatures or pressures

  Use of kinetic theory to explain the properties of solids, liquids and gases; description of solutions, solubility and precipitates; factors which affect volatility; colloids and their properties.
• **Atoms, elements and compounds:** *Matter is made of atoms, compounds are formed when atoms of different elements are chemically bonded*

Atomic structure and the properties of protons, neutrons and electrons; relative atomic mass; ions and how they are formed; properties of different elements are related to the structure of their atoms; chemical bonds including ionic bonds, covalent bonds and metallic bonds; bonding affects the physical properties of substances.

• **The periodic table:** *The periodic table displays all the elements and organises them according to their atomic structure*

Elements are listed in the periodic table in order of increasing atomic number; elements react according to their atomic structure; groups and periods; elements in the same group have similar atomic structures; properties of metals and non-metals; the reactivity series and displacement reactions; trends and patterns of the periodic table.

• **Chemical formulae:** *Chemical formulae are used to represent elements and compounds*

Chemical formula as a means of expressing the number and type of atoms that make up a particular compound; identification of elements and compounds from their chemical formulae; the formulae of some simple compounds; relative formula mass; empirical formulae.

• **Chemical reactions:** *Chemical reactions involve rearrangements of atoms to form new substances*

The principle of the conservation of mass; rearrangement of atoms during chemical reactions; collision theory relating to rate of chemical reactions – catalysts, concentration, surface area, temperature and pressure; balanced symbol equations to represent simple chemical reactions; use of state symbols; reversible reactions and equilibria; activation energy; use of the terms endothermic and exothermic; chemical reactions as the basis of biological systems; complete and incomplete combustion; redox reactions; monomers, polymers and polymerisation; neutralisation reactions; electrolysis.

• **Acids, bases and salts:**

The terms ‘acid’, ‘salt’, ‘base’ and ‘alkali’; equations to represent neutralisation reactions; pH of solutions is used to classify them as acidic, alkaline or neutral; indicators; why pH changes during a reaction between an acid and an alkali; acids and alkalis are classified as strong or weak according to their pH
6.2. The endeavour of chemistry

- **Development of new materials**
  New materials are designed and developed to meet specific requirements; risks of working with new reactions

- **Assessment of materials related to sustainability**
  Biodegradable and non-biodegradable materials; effects of using particular materials in a product over the complete life cycle

- **Sustainable process design**
  Refining processes to solve sustainability problems; the actual yield and theoretical yield; economic implications of reaction conditions that provide the greatest yield; costs, potential availability of materials and sustainability of the process; atom economy

- **Carbon chemistry**
  Carbon cycle; functional groups (alkanes, alkenes, alcohols etc.); carbon compounds are the basis of a range of fuels, products, food, flavourings, drugs; associated social/environmental/economic issues

- **Quantitative chemistry**
  Definition and calculation of concentrations; calculation of efficiency of processes; simple ratios and calculations of reacting masses or product masses; calculation of percentage yield; calculation of required volumes for particular dilutions; the mole and calculating molar mass

- **Chemical analysis and characterisation**
  Identifying ions in solution; monitoring concentrations of chemicals; selecting appropriate separation techniques including ion exchange; fractional distillation; bioleaching; purity and how impurities can result in unwanted by-products in reactions or unintended effects

- **Earth systems**
  Modelling earth systems, such as carbon dioxide and temperature using scientific data; the limits of models of earth systems; the extraction of a range of materials from the atmosphere, hydrosphere, biosphere and lithosphere.

6.3. Practical chemistry

By the age of 16 we would expect that every student has had opportunities to directly experience, and be confident carrying out a range of chemical syntheses, analyses and characterisations using the following practical techniques and procedures:
Preparation of an inorganic and possibly an organic substance: By careful mixing of reagents under controlled conditions:

- **Separating techniques for chemical mixtures using a range of equipment:** To include evaporation, filtration, distillation, crystallisation, chromatography, electrolysis
- **Measurement of volumes of liquids using a range of equipment:** To include beakers, measuring cylinders, pipettes, syringes and burettes
- **Measurement of rates of reaction:** To include collection of gas, loss of mass, precipitation reactions
- **Analysing unknown samples:** such as anion and cation testing (flame tests/precipitation reactions)
- **Titrations:** using a burette to identify unknown quantities
- **Reactivity series:** displacement reactions; metals and acids.

7. Physics content and ideas

Physics is a collection of ways of thinking that have led to a number of very successful descriptions and explanations of the way the world works. An education in physics develops these ways of thinking, which are valuable in their own right and transferable to many other contexts. It also develops an awareness of some general themes - big ideas - and an understanding of a core set of content and explanations within the domains of physics.

7.1. Big ideas in physics

The list below is a set of big ideas for 16 year olds. They are not intended as a description of physics but rather the impressions and ideas that all school children should experience and develop in their physics education – and that should remain ten years after they stop studying the discipline.

Some of the big ideas are thematic and others come from the domains of physics. They have been listed separately in the sections below. Within the domains of physics, we have included some indicative content – these are not big ideas themselves but represent some of the areas of study that might contribute to developing the big ideas.

**Themes**

- **Reductionism.** *Physics describes natural phenomena in terms of a small number of laws, which allow predictions to be made on whether and how things will happen.*
- **Universality.** *The laws of physics are universal - they work everywhere.*
- **Unification.** *There is a drive to reduce the number of laws to as small a number as possible, each one expressed in as economical a way as possible.*
- **Synoptic nature.** *Physics is an interlinked totality of ideas that must be consistent with each other. Problems can be approached from many different directions.*
• **Cause and effect.** Events can be discussed and understood in terms of causes and effects: what makes things happen the way they do.

• **Mathematical techniques.** Physical laws can be expressed in a mathematical form. Physicists develop mathematical models to describe and predict behaviour.

• **Conservation.** Some quantities (charge, mass/energy, matter & momentum) are conserved. These conservation laws lead to powerful restrictions on behaviour.

• **Equilibrium.** Equilibrium occurs when two or more external influences are in balance - balanced forces, balanced moments, balanced pressures, equal flows in and out.

• **Differences cause change.** For example temperature difference, pressure difference, potential difference, differences in concentration and unbalanced forces.

• **Inertia.** Things will tend to stay as they are (including moving at a constant speed) unless something causes them to change.

• **Dissipation.** Many processes have an element that is resistive and dissipative. Dissipation is a result of the tendency of a system to become more disordered.

• **Irreversibility.** Dissipative processes are irreversible. For example, they limit the usefulness and the lifetime of a resource and determine the arrow of time.

• **Fields.** Action at a distance can be understood in terms of fields.

• **Energy.** There is a useful accounting tool - energy - that, allows us to do calculations to find out, e.g. how long sources will last, or whether some events can happen.

**From the domains of physics**

• **Interactions:** There are interactions (forces) between objects that can change their shape or the way they are moving.

  Indicative content areas: Levers and moments; forces that act by contact or at a distance (friction, gravity, electrical and magnetic forces); balanced forces and equilibrium; work and energy stores.

• **Kinematics:** There are well-established laws of motion that predict the way that objects will move and interact with each other.

  Indicative content areas: Speed and acceleration; balanced forces and Newton’s first law; unbalanced forces, inertia, Newton’s second law; Newton’s third law, momentum; calculations using energy and power.

• **Waves:** Waves carry energy from a transmitter and can be detected by a receiver.

  Indicative content areas: Properties of sound – how we make and hear sounds; properties of light (brightness, shadows, straight lines, images, lenses and colour); properties of waves (refraction, reflection, frequency, wavelength and amplitude); models of radiation; ionising radiations.

• **Electricity and magnetism.** An electric current is the flow of charge in a circuit and allows us to use a remote supply to do work. Electricity and magnetism are intimately linked by basic laws of physics, a situation that has many important technological consequences.

  Indicative content areas: Electric charge; electric current in a complete electric circuit; voltage and resistance in a simple circuit; resistors in series and parallel; current in
parallel arms of a parallel circuit; potential difference across components in a series circuit; using energy and power to do calculations. Electromagnetic effects: electromagnetic induction; transformers and mains electricity.

- **Matter, particles, atoms and beyond.** *The properties of materials can be understood in terms of constituent particles, their motions and interactions.*

  Indicative content areas: The particle model of matter – kinetic theory; density, expansion, floating and convection; solids, liquids and gases; heating and cooling by conduction, radiation and evaporation; the structure of atoms.

- **Cosmology.** *Physics describes our place in the universe. It also provides theories and models for the origin of the universe and similar questions.*

  Indicative content areas: The solar system and the Earth’s place in it; the features and origins of elements, stars (including the Sun), galaxies and the Universe.

### 7.2. The endeavour of physics (thinking like a physicist)

We have referred to the ways of thinking that characterise and are developed by physics. The list below includes some of those ways of thinking:

- **critical thinking and scepticism:** puzzling away at something and taking account of all possible objections to find an explanation that they are certain works;
- **deep understanding:** looking for deeper and deeper explanations; not being satisfied with a superficial description; looking for the most fundamental answer that has predictive power across many domains;
- **seeking consistency:** testing that answers are consistent with experience and all other areas of physics;
- **reason and logic:** striving for logical consistency within arguments;
- **quantitative understanding:** realising that quantitative analysis is necessary for proper understanding;
- **models:** developing models (often mathematical) of systems to make predictions of their behaviour in a variety of circumstances;
- **simplification:** simplifying physical situations to their core elements to enable the use of quantitative models to explain or predict phenomena;
- **approximation and other techniques:** making back-of-the-envelope calculations to test the plausibility of ideas; using techniques that consider limiting or extreme cases;
- **isolating:** isolating physical phenomena to test ideas experimentally;
- **using experiments to test ideas:** refining models through the iterative sequence of experiment -> model -> prediction -> test;
- **excising prejudice:** being able to step outside immediate experience and accept explanations that are beyond ‘common sense’;
7.3. Practical physics

We would expect that every 16 year old has had opportunities to develop a range of practical techniques, procedures and methods (see section 4.2). They should have experienced and be confident working with the indicative examples below:

- **electric circuits**: wiring simple series and parallel circuits and measuring potential differences and currents within them using ammeters and voltmeters (analogue and digital);
- **materials**: testing the extension of a spring, using thermometers (with appropriate ranges) for measuring the temperature of a cooling object, determining specific heat capacities and investigating the behaviour of gases;
- **forces**: balancing levers and determining a centre of mass; using newton meters (with different ranges);
- **kinematics**: measuring distance, determining speed and acceleration, investigating the effect on acceleration of changing the force on and the mass of the object being accelerated;
- **optical devices**: focusing a lens, determining the power of a lens, building a pin hole camera or telescope, investigating reflection and refraction in solid transparent blocks, colour mixing;
- **waves**: experiments with sound waves and waves in ripple tanks, measuring the speed of sound;
- **radiations**: experiments with heating and cooling by radiation.

8. Earth Science

Earth Science relies on many of the approaches and ideas of the science disciplines. The big ideas in Earth Science can be developed within the sciences and provide useful and important contexts to illustrate the use of scientific knowledge and ways of thinking and working scientifically.

8.1. Big ideas in Earth Science

- **The fossil record** - informs our understanding of past environments and the development of life and the planet
- **The rock cycle** – rocks are not static; they are formed and reformed in a continuing cycle that is affected by physical and chemical processes
- **The Earth has structure** – there is evidence that supports theories about how the composition of the Earth varies from the surface to the core
- **Climate** – the Earth’s climate is not fixed: it has varied through the Earth’s history and continues to do so
- **Plate tectonics** – a theory of how land formations have come about and why there is geological activity at the plate margins.