



Department
for Education

Science key stage 4

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Introduction

Teaching in the sciences in key stage 4 continues with the process of building upon and deepening understanding of ideas developed in earlier key stages in the subject disciplines of biology, chemistry and physics.

For some students, studying the sciences in key stage 4 provides the platform for more advanced studies, establishing the basis for a wide range of careers. For others, it will be their last formal study of subjects that provide the foundations for understanding the natural world and will enhance their lives in an increasingly technological society.

Scientific understanding is changing our lives and is vital to the world's future prosperity, and all students should be taught essential aspects of the knowledge, methods, processes and uses of science. They should be helped to appreciate the achievements of science in showing 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 inter-linked, and which 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 interactions between different objects and systems
- that many such interactions occur over a distance and over time
- 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 sciences should be taught in ways that help students to develop curiosity about the natural world, insight into working scientifically, and appreciation of the relevance of science to their everyday lives, so that students:

- 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 enquiry that help them to answer scientific questions about the world around them;
- develop and learn to apply observational, practical, modelling, enquiry, problem-solving skills and mathematical 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.

Curricula at key stage 4 should comprise approximately equal proportions of biology, chemistry and physics. The relevant mathematical skills required are covered in the programme of study for mathematics and should be embedded in the science context.

‘Working scientifically’ is described separately at the beginning of the programme of study, but must always be taught through and clearly related to substantive science content in the programme of study. Teachers should feel free to choose examples that serve a variety of purposes, from showing how scientific ideas have developed historically to reflecting modern developments in science and informing students of the role of science in understanding the causes of and solutions for some of the challenges facing society, such as climate change, food security, water supply, health and energy issues.

The scope and nature of their study should be broad, coherent, practical and satisfying, and thereby encourage students to be inspired, motivated and challenged by the subject and its achievements.

Working scientifically

Through the content across all three disciplines, students should be taught so that they develop understanding and first-hand experience of:

1. The development of scientific thinking

- understanding how scientific methods and theories develop over time
- using a variety of models to develop scientific explanations and understanding
- appreciating the power and limitations of science and considering ethical issues which may arise
- explaining everyday and technological applications of science; evaluating associated personal, social, economic and environmental implications; and making decisions based on the evaluation of evidence and arguments
- evaluating risks both in practical science and the wider societal context, including perception of risk.
- recognising the importance of peer review of results and of communication of results to a range of audiences.

2. Experimental skills and strategies

- using scientific theories and explanations to develop hypotheses
- planning experiments to make observations, test hypotheses or explore phenomena
- applying a knowledge of a range of techniques, apparatus, and materials to select those appropriate to the experiment
- carrying out experiments appropriately having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations
- recognising when to apply a knowledge of sampling techniques to ensure any samples collected are representative
- making and recording observations and measurements using a range of apparatus and methods
- evaluating methods and suggesting possible improvements and further investigations.

3. Analysis and evaluation

- applying the cycle of collecting, presenting and analysing data, including:
 - presenting observations and other data using appropriate methods
 - translating data from one form to another
 - carrying out and representing mathematical and statistical analysis
 - representing distributions of results and making estimations of uncertainty
 - interpreting observations and other data, including identifying patterns and trends, making inferences and drawing conclusions
 - presenting reasoned explanations, including relating data to hypotheses
 - being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error
- communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations.

4. Vocabulary, units, symbols and nomenclature

- developing their use of scientific vocabulary and nomenclature
- recognising the importance of scientific quantities and understanding how they are determined
- using SI units and IUPAC chemical nomenclature unless inappropriate
- using prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano)
- interconverting units
- using an appropriate number of significant figures in calculations.

Subject content – Biology

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.

Students 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 can be illustrated in the separate topics set out below. These ideas 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 life processes to be performed more 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 the process of natural selection and accounts both for biodiversity and how organisms are all related to varying degrees.

Students should be taught about:

Cell biology

- cells as the basic structural unit of all organisms; adaptations of cells related to their functions; the main sub-cellular structures of eukaryotic and prokaryotic cells
- stem cells in animals and meristems in plants

- enzymes
- factors affecting the rate of enzymatic reactions
- the importance of cellular respiration; the processes of aerobic and anaerobic respiration
- carbohydrates, proteins, nucleic acids and lipids as key biological molecules.

Transport systems

- the need for transport systems in multicellular organisms, including plants
- the relationship between the structure and functions of the human circulatory system.

Health, disease and the development of medicines

- the relationship between health and disease
- communicable and non-communicable diseases
- bacteria, viruses and fungi as pathogens in animals and plants
- body defences against pathogens and the role of the immune system against disease
- reducing and preventing the spread of infectious diseases in animals and plants
- the process of discovery and development of new medicines
- the impact of lifestyle factors on the incidence of non-communicable diseases.

Coordination and control

- principles of nervous coordination and control in humans
- the relationship between the structure and function of the human nervous system
- the relationship between structure and function in a reflex arc
- principles of hormonal coordination and control in humans
- hormones in human reproduction, hormonal and non-hormonal methods of contraception
- homeostasis.

Photosynthesis

- photosynthesis as the key process for food production and therefore biomass for life
- the process of photosynthesis
- factors affecting the rate of photosynthesis.

Ecosystems

- levels of organisation within an ecosystem
- some abiotic and biotic factors which affect communities; the importance of interactions between organisms in a community
- how materials cycle through abiotic and biotic components of ecosystems
- the role of microorganisms (decomposers) in the cycling of materials through an ecosystem
- organisms are interdependent and are adapted to their environment
- the importance of biodiversity
- methods of identifying species and measuring distribution, frequency and abundance of species within a habitat
- positive and negative human interactions with ecosystems.

Evolution, inheritance and variation

- the genome as the entire genetic material of an organism
- how the genome, and its interaction with the environment, influence the development of the phenotype of an organism
- the potential impact of genomics on medicine
- most phenotypic features being the result of multiple, rather than single, genes
- single gene inheritance and single gene crosses with dominant and recessive alleles
- sex determination in humans
- genetic variation in populations of a species
- the process of natural selection leading to evolution
- the evidence for evolution
- developments in biology affecting classification

- the importance of selective breeding of plants and animals in agriculture
- the uses of modern biotechnology including gene technology; some of the practical and ethical considerations of modern biotechnology.

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Subject content – Chemistry

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.

Students 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 can be illustrated in the separate topics set out below. These ideas include:

- matter is composed of tiny particles called atoms and there are about 100 different naturally-occurring types of atoms called elements
- elements show periodic relationships in their chemical and physical properties
- these periodic properties can be explained in terms of the atomic structure of the elements
- atoms bond either by 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
- reactions can occur when molecules collide and do so at different rates due to differences in molecular collisions
- 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 nor destroyed.

Students should be taught about:

Atomic structure and the Periodic Table

- a simple model of the atom consisting of the nucleus and electrons, relative atomic mass, electronic charge and isotopes
- the number of particles in a given mass of a substance
- the modern Periodic Table, showing elements arranged in order of atomic number

- position of elements in the Periodic Table in relation to their atomic structure and arrangement of outer electrons
- properties and trends in properties of elements in the same group
- characteristic properties of metals and non-metals
- chemical reactivity of elements in relation to their position in the Periodic Table.

Structure, bonding and the properties of matter

- changes of state of matter in terms of particle kinetics, energy transfers and the relative strength of chemical bonds and intermolecular forces
- types of chemical bonding: ionic, covalent, and metallic
- bulk properties of materials related to bonding and intermolecular forces
- bonding of carbon leading to the vast array of natural and synthetic organic compounds that occur due to the ability of carbon to form families of similar compounds, chains and rings
- structures, bonding and properties of diamond, graphite, fullerenes and grapheme.

Chemical changes

- determination of empirical formulae from the ratio of atoms of different kinds
- balanced chemical equations, ionic equations and state symbols
- identification of common gases
- the chemistry of acids; reactions with some metals and carbonates
- pH as a measure of hydrogen ion concentration and its numerical scale
- electrolysis of molten ionic liquids and aqueous ionic solutions
- reduction and oxidation in terms of loss or gain of oxygen.

Energy changes in chemistry

- Measurement of energy changes in chemical reactions (qualitative)
- Bond breaking, bond making, activation energy and reaction profiles (qualitative).

Rate and extent of chemical change

- factors that influence the rate of reaction: varying temperature or concentration, changing the surface area of a solid reactant or by adding a catalyst
- factors affecting reversible reactions.

Chemical analysis

- distinguishing between pure and impure substances
- separation techniques for mixtures of substances: filtration, crystallisation, chromatography, simple and fractional distillation
- quantitative interpretation of balanced equations
- concentrations of solutions in relation to mass of solute and volume of solvent.

Chemical and allied industries

- life cycle assessment and recycling to assess environmental impacts associated with all the stages of a product's life
- the viability of recycling of certain materials
- carbon compounds, both as fuels and feedstock, and the competing demands for limited resources
- fractional distillation of crude oil and cracking to make more useful materials
- extraction and purification of metals related to the position of carbon in a reactivity series.

Earth and atmospheric science

- evidence for composition and evolution of the Earth's atmosphere since its formation
- evidence, and uncertainties in evidence, for additional anthropogenic causes of climate change
- potential effects of, and mitigation of, increased levels of carbon dioxide and methane on the Earth's climate
- common atmospheric pollutants: sulfur dioxide, oxides of nitrogen, particulates and their sources
- the Earth's water resources and obtaining potable water.

Subject content – Physics

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.

Students 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 can be illustrated in the separate topics set out below. These ideas 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.

Students should be taught about:

Energy

- energy changes in a system involving heating, doing work using forces, or doing work using an electric current: calculating the stored energies and energy changes involved
- power as the rate of transfer of energy,
- conservation of energy in a closed system, dissipation
- calculating energy efficiency for any energy transfers
- renewable and non-renewable energy sources used on Earth, changes in how these are used.

Forces

- forces and fields: electrostatic, magnetic, gravity
- forces as vectors
- calculating work done as force x distance; elastic and inelastic stretching
- pressure in fluids acts in all directions: variation in Earth's atmosphere with height, with depth for liquids, up-thrust force (qualitative).

Forces and motion

- speed of sound, estimating speeds and accelerations in everyday contexts
- interpreting quantitatively graphs of distance, time, and speed
- acceleration caused by forces; Newton's First Law
- weight and gravitational field strength
- decelerations and braking distances involved on roads, safety.

Wave motion

- amplitude, wavelength, frequency, relating velocity to frequency and wavelength
- transverse and longitudinal waves
- electromagnetic waves, velocity in vacuum; waves transferring energy; wavelengths and frequencies from radio to gamma-rays
- velocities differing between media: absorption, reflection, refraction effects
- production and detection, by electrical circuits, or by changes in atoms and nuclei
- uses in the radio, microwave, infra-red, visible, ultra-violet, X-ray and gamma-ray regions, hazardous effects on bodily tissues.

Electricity

- measuring resistance using p.d. and current measurements
- exploring current, resistance and voltage relationships for different circuit elements: making graphical representations of these
- quantity of charge flowing as the product of current and time
- drawing circuit diagrams; exploring equivalent resistance for resistors in series

- the domestic a.c. supply; live, neutral and earth mains wires, safety measures
- power transfer related to p.d. and current, or current and resistance.

Magnetism and electromagnetism

- exploring the magnetic fields of permanent and induced magnets, and the Earth's magnetic field, using a compass
- magnetic effects of currents, how solenoids enhance the effect
- how transformers are used in the national grid and the reasons for their use.

The structure of matter

- relating models of arrangements and motions of the molecules in solid, liquid and gas phases to their densities
- melting, evaporation, and sublimation as reversible changes
- calculating energy changes involved on heating, using specific heat capacity; and those involved in changes of state, using specific latent heat
- links between pressure and temperature of a gas at constant volume, related to the motion of its particles (qualitative).

Atomic structure

- the nuclear model and its development in the light of changing evidence
- masses and sizes of nuclei, atoms and small molecules
- differences in numbers of protons, and neutrons related to masses and identities of nuclei, isotope characteristics and equations to represent changes
- ionisation; absorption or emission of radiation related to changes in electron orbits
- radioactive nuclei: emission of alpha or beta particles, neutrons, or gamma-rays, related to changes in the nuclear mass and/or charge
- radioactive materials, half-life, irradiation, contamination and their associated hazardous effects, waste disposal
- nuclear fission, nuclear fusion and our Sun's energy
- the main features of the solar system.



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