



Department
for Education

Science

Programme of study for Key Stage 4

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Purpose of study

A high-quality science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics. Science has changed our lives and is vital to the world's future prosperity, and all pupils should be taught essential aspects of the knowledge, methods, processes and uses of science. Through building up a body of key foundational knowledge and concepts, pupils should be encouraged to recognise the power of rational explanation and develop a sense of excitement and curiosity about natural phenomena. They should be encouraged to understand how key foundational knowledge and concepts can be used to explain what is occurring, predict how things will behave, and analyse causes. This foundational understanding should be consolidated through their appreciation of the specific applications of science in society and the economy.

Aims

The National Curriculum for science aims to ensure that all pupils:

- 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 science enquiries that help them to answer scientific questions about the world around them
- are equipped with the scientific knowledge required to understand the **uses and implications** of science, today and for the future.

Attainment targets

By the end of each key stage, pupils are expected to know, apply and understand the matters, skills and processes specified in the relevant programme of study

Working scientifically

Through the content across all three disciplines, pupils should be taught to:

Experimental skills and investigations

- use scientific theories, models and explanations to develop hypotheses
- plan investigations to make observations and to test hypotheses, including identifying variables as independent, dependent or control, and measure and consider other factors that need to be taken into account when collecting evidence
- use knowledge of techniques, apparatus, and materials, during fieldwork and laboratory work, select those that are appropriate to the investigation, and use them appropriately, adapting apparatus and strategy flexibly when problems arise and paying attention to health and safety
- make and record observations and measurements using a range of methods; evaluate methods and suggest possible improvements and further investigations
- measure and manipulate concentrations

Handling information and problem solving

- present observations and data using appropriate methods and carry out and represent mathematical and statistical analysis; represent random distribution of results and estimate uncertainty; interpret observations and data, including identifying patterns and trends and use observations, measurements and data to make inferences and draw conclusions
- evaluate data critically, showing awareness of potential sources of random variations and systematic errors, and suggest improvements
- communicate the scientific rationale for the investigation and the methods used, giving accounts of findings, reasoned explanation of data in relation to hypotheses and reasoned conclusions through written reports and electronic presentations

Scientific attitudes

- pay attention to objectivity and concern for validity, accuracy, precision and measurement of uncertainty
- understand that scientific methods and theories develop as scientists modify earlier explanations to take account of new evidence and ideas, together with the importance of publishing results and peer review
- understand the power and limitations of science and potential ethical questions and debates
- evaluate risks

Measurement

- understand and use SI units and IUPAC chemical nomenclature
- convert units.

Subject content

Biology

Structure and function of living organisms

Pupils should be taught about:

Cell biology

- the impact of electron microscopy on our understanding of sub-cellular structure and functions, especially the nucleus, endoplasmic reticulum, mitochondria, ribosomes, chloroplasts and cell membranes
- similarities and differences in the structure and function of prokaryotic and eukaryotic cells; growing prokaryotic organisms using aseptic techniques
- the stages of a cell cycle and processes of growth, maintenance and reproduction
- the importance of stem cells in embryonic and adult animals and of meristems in plants
- differentiation, cell specialisation and cell adaptations for function in animals and plants
- mechanism of transport within and between cells, including diffusion, osmosis and active transport
- how cellular respiration enables metabolic processes in cells; the chemistry of aerobic and anaerobic respiration and chemical equations for aerobic and anaerobic respiration properties; and the roles of intracellular and extracellular enzymes, including active sites and specificity
- the factors affecting the rate of enzymatic reactions, including rate calculations, graphical representation of data and data interpretation

Transport systems in people and plant

- the need for a transport system in multicellular organisms, including surface area:volume calculations
- the structure and function of the heart, including control of the muscular contractions and the working of the valves both in the heart and the vessels
- the structure and function of arteries, veins and capillaries, including the exchange of substances between capillaries and tissues
- the components of the blood and their functions: to include red blood cells, white blood cells, platelets and plasma
- the structure and function of root hair cells and the importance of diffusion and osmosis in water movement and active transport in mineral ion movements in plants
- the processes of transpiration and translocation through the xylem and phloem, including experimental work and rate calculations
- the effects of variation of air, movement, temperature, humidity and light intensity on transpiration and the process of wilting, including rate calculations

Health, disease and the development of medicines

- the relationship between health and disease
- different types of disease – infectious and non-communicable diseases (NCDs) – and the interactions between them
- the role of bacteria, viruses and fungi in causing infectious disease in animals and plants
- the immune system and the body's defence against pathogens, including in the context of transplant surgery and autoimmune disease
- the immune system: structure, function and responses, including non-specific (such as those of the skin and white blood cells) and specific (including the formation of antibodies in response to foreign antigens)
- the importance of medicines, including vaccines in preventing and treating disease
- the discovery and development of new medicines, including their pre-clinical and clinical testing
- the effect of exercise on the human circulatory system; the causes and current and potential treatments of cardiovascular disease, including lifestyle changes, stents and stem cells

Coordination and control in animals and plants

- how different living organisms respond to their environment
- the structure and function of the nervous system: brain, spinal cord, sensory and motor neurones
- the pathway taken by impulses in response to stimuli
- the reflex arc, rapid response to a stimulus, possible and reflex actions
- the main parts of the eye and their functions; limitations and defects of the eye and ways of overcoming these, including the use of lasers and stem cells (reference should be made to the wave model of light)
- the main parts of the ear and their functions; limitations and defects of the ear and ways of overcoming these, including cochlear implants (reference should be made to the wave model of sound)
- the brain as a co-ordination centre to include: cerebral hemispheres, cerebellum, brain stem (medulla), pituitary gland and hypothalamus; the role of technology and drugs in investigating and repairing the brain and nervous system
- hormones as chemical messages used in coordination and control, and the differences between plant and animal hormones
- the nature of hormonal co-ordination and control in humans: the main endocrine glands, feedback control and the role of thyroxine, adrenaline, glucagon and insulin, including thyroid disease and Type 1 and Type 2 diabetes
- hormones in human reproduction (FSH, LH, oestrogen, progesterone and testosterone), the control of the menstrual cycle, and their use in reproductive technologies, including IVF; contraception, including hormonal methods
- hormonal control of plant growth and development, including measurement of phototropic responses and human use of plant hormones

Homeostasis and excretion

- the importance of maintaining a constant internal environment
- the removal of the waste products of body metabolism (carbon dioxide and urea)
- osmoregulation and the role of the kidneys in water balance
- the control of body temperature.

Energy flow and material cycles

Pupils should be taught about:

Photosynthesis

- photosynthesis as the key process for life in terms of food security and the sustainability of biodiversity
- the chemical equation for photosynthesis
- how plants and algae use the products of photosynthesis
- measuring the effects of varying light intensity, the wavelength of light, carbon dioxide concentration and temperature on the rate of photosynthesis, including graphical treatment of the data and the relationships of these factors to the distribution of plants in different habitats

Material cycles

- how materials cycle through the biotic and abiotic components of ecosystems
- decomposition and factors influencing the rate of decomposition in aerobic, anaerobic and artificial environments, including refuse disposal and biogas generators
- the importance of microorganisms as decomposers in the cycling of material, such as nitrates and carbon in the environment, and nitrogen-fixing bacteria in the root nodules of plants
- the carbon cycle, emphasising the relationship between respiration and photosynthesis and how carbon cycles through abiotic and biotic factors in an ecosystem
- the importance of water in biological systems.

Interactions and interdependencies

Pupils should be taught about:

Ecosystems

- levels of organisation: species, population, community, ecosystem, biome and biosphere
- components of an ecosystem (abiotic factors and biotic community)
- relationships among organisms in an ecosystem
- the functioning of ecosystems: pyramids of biomass and energy transfer between different trophic levels, including calculating the loss of biomass between levels

Human interactions with ecosystems

- the importance of biodiversity in ecosystems
- identifying and classifying local species and using keys
- measuring the distribution, frequency and abundance of species in a range of habitats and explaining outcomes in terms of abiotic and biotic factors
- measuring changes in the distribution and abundance of organisms as a way of measuring and monitoring change in ecosystems
- positive and negative human interactions with ecosystems
- the biological challenges of increasing food yield using fewer resources.

Genetics and evolution

Pupils should be taught about:

Reproduction

- the importance of reproduction and the differences between sexual reproduction and asexual reproduction
- asexual reproduction as a process that results in genetically identical offspring (clones) from one parent and its importance in colonising a habitat
- sexual reproduction as a process involving fusion of nuclei from genetically different gametes to form a zygote and the production of genetic variation in plants and animals
- the development of biotechnologies using cloning in agriculture and other embryonic and adult stem cells in medicine

Evolution, inheritance and variation

- the genome as the sum total of the genetic material in an organism
- gene expression as the mechanism through which information in the genome controls the development of an organism
- the potential impact of genomics on medicine
- how sex is determined in humans and other organisms
- genetic terms, including dominant allele, recessive allele, homozygous, heterozygous phenotype and genotype
- the mechanism of monohybrid inheritance when there are dominant and recessive alleles, including simple ratios and the probability of certain genotypes and phenotypes occurring, with reference to some genetic disorders
- the causes of mutations and the source of genetic variation
- mutations in gametes which can result in phenotypic changes in offspring
- the evolution of new species over time through natural selection
- the ways in which genetic variation and environmental factors contribute to evolution, including bacterial resistance to antibiotics, and the evolution of the horse and human beings
- the diversity of organisms and how each adapts to a particular environment as a result of evolution
- the evidence for evolution from geology, fossils, comparative anatomy and molecular biology
- common descent
- the complementary work of Darwin and Mendel
- the impact of developments in evolutionary biology on classification: the three domain model based on DNA analysis; the phenotype-based model of phylum, class, order, family, genus and species
- the historical importance of artificial selection on plants and animals in agriculture
- genetic engineering and the uses of biotechnology in modern agriculture, food production and medicine, including practical and ethical problems in the development of the technology.

Chemistry

Pupils should be taught about:

Pure and impure substances

- using techniques for separating mixtures of substances, including filtration, crystallisation, distillation, fractional distillation and chromatography in a variety of phases
- measuring the purity of substances
- identifying ions and gases by chemical and spectroscopic means

The particulate nature of matter

- states of matter and change of state in terms of energy transfers and the relative strength of chemical bonds and intermolecular forces
- bulk and surface properties of matter and nanoparticles

Atoms, elements and compounds

- a simple model of the atom, including protons, neutrons and electrons, relative atomic mass, electronic charge and isotopes
- the calculation of relative atomic mass from isotopic percentages
- different kinds of chemical bonds: ionic, covalent, metallic bonding
- how chemical bonds and their arrangement determine varying properties of materials, ionic compounds, molecules, macromolecules, metals and semi-conductors
- allotropes and carbon

Chemical reactions

- redox reactions (oxidation and reduction) as loss of electrons and gain of electrons
- displacement reactions as redox reactions
- representations using half equations and ionic equations
- factors that influence the rate of reaction, including catalysts
- half-life of first order reactions
- reversible reactions and the concept of dynamic equilibrium
- the balance between equilibrium position and rate in industrial processes; the Haber process
- agricultural productivity and the use of nitrogen, phosphorus and potassium-based fertilisers

Energetics

- exothermic and endothermic reactions in terms of making and breaking chemical bonds, including reaction profiles (quantitative)

Acids, alkalis and neutralisation

- the definition of acids, bases and alkalis with reference to hydrogen and hydroxide ions
- neutralisation reactions
- acids and alkalis: dilute and concentrated, weak and strong

The Periodic Table

- the principles underpinning the Mendeleev Periodic Table
- the positions of elements in the Periodic Table in relation to their atomic structure and combining power
- the properties and trends in properties of elements in Groups 0, 1 and 7
- the properties of transition metals
- predicting chemical properties, reactivity and type of reaction of elements from their position in the Periodic Table

Metals

- the reactivity series of metals as the tendency of a metal to form its positive ion
- the physical and chemical properties of different metals related to their atomic structure and position on the Periodic Table
- different methods for extracting and purifying metals with reference to the reactivity series: copper, aluminium and titanium
- the production of alloys, including steel
- properties and uses of different metals and alloys
- causes of corrosion and their mitigation

Earth science

- carbon dioxide and methane as greenhouse gases
- carbon capture and storage
- common pollutants and their sources: carbon monoxide, sulphur dioxide, oxides of nitrogen, ozone and particulates
- the Earth's water resources and obtaining potable water
- calcium carbonate as a raw material for the construction industry

Electrochemistry

- molten ionic and aqueous ionic liquids
- products of electrolysis of various substances
- reactions at the electrodes
- the use of electrochemistry for extracting and purifying some metals
- fuel cells

Organic chemistry

- homologous series, alkanes and alkenes
- alcohols
- the use of carbon compounds as fuels and feedstock for the chemical industry
- fractional distillation of crude oil and cracking
- addition and condensation polymerisation
- naturally occurring and synthetic macromolecules/polymers, including DNA, natural oils and hydrogenation
- the uses of polymers

Quantitative chemistry

- the quantitative interpretation of balanced equations, including calculations involving non-integer reacting masses
- calculations comparing yield and atom economy of chemical reactions
- the mole concept applied to masses of pure substances, volumes of gases and concentrations of solutions
- methods for calculating and determining the concentration of solutions
- the calculation of the amounts of material produced in electrolysis.

Physics

Energy

Pupils should be taught about:

Changes and differences

- differences of some kind as conditions for change: e.g. in height, electrical potential, temperature
- how change driven by a difference tends to reduce that difference: weights fall to the ground, pressure differences are reduced, batteries run down, objects come to the same temperature

Changes as energy transfer

- changes involving transfers of energy between different parts of a system: such as a falling object hitting the ground, movements in other types of field, objects being stretched or compressed, solids melting, an electric kettle heating water but also the air around it, fuels burning when reacting with oxygen
- quantitative calculations of such transfers: of work done; as electrical charge (charge x potential difference); heating and cooling as transfer of internal energy (mass x temperature rise x specific heat)
- power as rate of transfer

Conservation and dissipation

- changes producing no net loss of energy: energy is conserved but dissipation raises temperature and is unavoidable
- measures of efficiency
- reducing unwanted energy transfers: e.g. through lubrication, thermal insulation
- national and global fuel resources, renewable energy sources.

Motion and forces

Pupils should be taught about:

Motion

- velocity as speed in a given direction
- acceleration = change in velocity ÷ time; distance/time and velocity/time graphs and their interpretation
- estimating sizes of everyday velocities and accelerations
- relative velocity, net velocity in head-on collision

Motion and forces

- movement without forces; skating and sliding in low friction; difficulty of starting or stopping
- constant velocity if no net force: Newton's First Law
- acceleration caused by unbalanced force; the effect of a force depending on the object being moved; mass as the ratio of force to acceleration (inertia); Newton's Second Law
- direction of change and direction of resultant force; force as a vector

Collisions and momentum

- defining momentum as mass x velocity; speeds before and after objects collide: conservation of momentum
- force as rate of change of momentum: Newton's Third Law.

Waves

Pupils should be taught about:

Wave properties

- general properties of all waves, including reflection, refraction and superposition
- speed: frequency x wavelength

Sound in matter

- the range of frequencies of sound, below and above the audible; sound travelling at different speeds through different substances; sound waves in rocks and water, and reflections detecting subterranean structures; earthquake detection
- ultrasound for medical diagnosis
- resonance effects and feedback

Electromagnetic spectrum

- the range of frequencies of light in visible parts of the electromagnetic spectrum: higher frequencies: gamma rays, X-rays, ultra-violet; lower frequencies: infra-red, microwaves, radio waves

Waves as carriers

- waves carrying energy: e.g. radiation from Sun, infra-red radiation, ocean waves, seismic waves
- the uses of electromagnetic waves to carry information, by variations in amplitude and/or frequency; digital sampling of analogue information.

Electricity and electromagnetism

Pupils should be taught about:

Electric circuits

- calculations of current and potential difference: for series circuits (same currents, resistances add); for parallel circuits (same potential differences, reciprocals of resistance, i.e. conductances add)
- symbolic representations of circuits
- $V=I \times R$ and power transferred = $V \times I$ and $I^2 \times R$

Direct current (DC) and alternating current (AC)

- domestic mains: the ring circuit; potential difference and frequency; fuses, live, neutral and earth; safety
- the national grid and energy transfer from power stations to industry and homes
- high voltage transmission and efficiency

Energy and electricity

- heating effects of currents: power and energy calculations of energy transfers – from batteries, dynamos, mains – to heated materials, to work by electric motors

Static electricity and electric fields

- attraction and repulsion between like and unlike charges
- electric field forces acting over a distance, and increasing with decreased distance
- sparks between charged bodies; lightning

Magnetism and electromagnetism

- magnetic effects: action at a distance; magnetic fields
- ferromagnets; induced magnetism in some materials
- electromagnetic induction effect of changing fields; AC generators and transformers

Sensors and sources

- laboratory and commercial uses of a range of electronic sensors: e.g. position and motion, light and temperature, sound and vibration, force and stress
- oscillating currents as generators of electromagnetic waves; transmitting and detecting aerials; radio direction finders; radar.

Matter

Pupils should be taught about:

Pressure

- pressure in gases and particle movement; pressure as a scalar quantity, acting in all directions
- the kinetic model of gases; changes in pressure, temperature and volume related by $pV=RT$

Changes in solids

- changes of shape in solids: stretching, compressing and bending
- stress as a vector: the force per unit area in such changes
- shear stress and friction
- energy stored changes as distortion changes
- elastic and inelastic changes
- the internal structure of the Earth; changes of pressure and temperature with depth

Changes in atoms

- ionisation in static electricity; also by matter absorbing radiation
- other changes from absorption and emission associated with specific frequencies; links to nuclear model; emissions of ionising radiations, X-rays and gamma rays at higher frequencies of the electromagnetic spectrum
- emissions of particles and electrons; beta and alpha particles
- half-lives
- isotopes
- nuclear fission as energy source

Applications of radiation with matter

- radiations for forming images of internal structures in matter, including for diagnosis in medicine and for therapy
- the hazards for biological tissue of contamination and irradiation.



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