Department for Education

Science

GCSE subject content and assessment objectives

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Contents

Introduction

These GCSE subject criteria set out the knowledge, understanding, skills and assessment objectives common to all GCSE specifications in biology, chemistry, physics and combined double award science so ensuring progression from key stage 3 national curriculum requirements and the possibilities for development into A level.

They provide the framework within which awarding organisations create the detail of the subject specification.

Subject aims and learning outcomes

This document sets out the learning outcomes and content coverage required for GCSEs in the sciences. In subjects such as the sciences, where topics are taught in progressively greater depth over the course of key stage 3 and key stage 4, GCSE outcomes may reflect or build upon subject content which is typically taught at key stage 3. There is no expectation that teaching of such content should be repeated during the GCSE course where it has already been covered at an earlier stage.

GCSE study in the sciences provides the foundations for understanding the material world. Science 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.

These essential aspects should be studied in ways that help students to develop curiosity about the natural world, insight into how science works, and appreciation of its relevance to their everyday lives. The scope and nature of such study should be broad, coherent, practical and satisfying, and thereby encourage students to be inspired, motivated and challenged by the subject and its achievements.

GCSE specifications in the sciences should enable students to:

- develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics
- develop understanding of the nature, processes and methods of science, through different types of scientific enquiries that help them to answer scientific questions about the world around them
- develop and learn to apply observational, practical, modelling, enquiry and problem-solving skills, both in the laboratory 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.

Overall, students 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 are of universal application. Some of these apply across and between the three sciences, whilst others are given emphasis mainly in the separate subjects of biology, chemistry and physics. However, there are some ideas about science which have more general application, including the assumption that every effect has one or more cause and that scientific explanations, theories and models are those that best fit the facts known at a particular time.

The content below also sets out the mathematical skills required for each science discipline. Awarding organisations should go up to, but not beyond, the mathematical requirements specified in GCSE Mathematics.

Subject content

Biology

Biology is the science of living organisms 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.

This content sets out the full range of content for GCSE biology and the biology component of the combined double award in science. Awarding organisations may, however, use any flexibility to increase depth, breadth or context within the specified topics or to consolidate teaching of the subject content.

Statements below in **bold text** apply only to GCSE specifications in single award biology. Statements in [square brackets] apply only to specifications in combined double award science.

Scope of study

GCSE specifications should require students to:

Cell biology

Prokaryotic and eukaryotic cells

- describe a cell as the basic structural unit of all organisms
- describe the main sub-cellular structures of eukaryotic cells (plants and animals) and prokaryotic cells
- relate sub-cellular structures to their functions, especially the nucleus/genetic material, plasmids, endoplasmic reticulum, mitochondria, ribosomes, chloroplasts and cell membranes
- **evaluate the impact of electron microscopy on our understanding of sub-cellular structures including the nucleus, plasmids, mitochondria, chloroplasts and ribosomes**
- explain the aseptic techniques used in culturing microorganisms.

Growth and development of cells

- **describe the cell cycle and** explain the importance of mitotic cell division in growth
- **explain how errors in mitotic cell division may result in the formation of**

cancer cells

- describe cell differentiation
- relate the adaptations of specialised cells to their functions
- explain the importance of meiotic cell division in halving the chromosome number to form gametes.

Stem cells

- **recognise** [describe] the function of stem cells in embryonic and adult animals and meristems in plants
- discuss some of the issues concerning the uses of stem cells in medicine.

Transport in cells

- describe and explain how substances are transported into and out of cells through diffusion, osmosis and active transport.

Cell metabolism

- explain the mechanism of enzyme action including the active site and enzyme specificity
- **recall the difference between intracellular and extracellular enzymes**
- **recognise that cellular respiration is an exothermic reaction which enables metabolic processes in cells**
- compare the processes of aerobic and anaerobic respiration
- describe some anabolic and catabolic processes in living organisms including the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, lipids and proteins
- explain that anabolism + catabolism = metabolism.

<u>Use of mathematics</u>

- demonstrate an understanding of number, size and scale and the quantitative relationship between units
- use estimations and explain when they should be used
- calculate surface areas and volumes of simple shapes
- calculate surface area:volume ratios
- understand and use percentiles and calculate percentage gain and loss of mass
- carry out rate calculations for chemical reactions
- compare growth rate changes

- calculate with numbers written in standard form

Transport systems

Transport systems in multicellular organisms

- describe some of the substances which require transporting into and out of living organisms, to include oxygen, carbon dioxide, water, dissolved food molecules, mineral ions and urea
- explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area:volume ratio.

Human circulatory system

- describe the human circulatory system
- relate the structure of the heart and the blood vessels and the blood to their functions
- recognise the main components of the blood as red blood cells, white blood cells, platelets and plasma and explain the functions of each.

Transport systems in plants

- describe the structure of xylem and phloem and link these to their functions in the plant
- explain how water and mineral ions are taken up by plants, relating the structure of the root hair cells to their function
- [state that plants have transport tissues called xylem and phloem]
- [recall that water and minerals are transported in the xylem and that the products of photosynthesis are transported in the phloem]
- explain the processes of transpiration and translocation, linking the structure of the stomata to their function
- predict 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.

<u>Use of mathematics</u>

- calculate surface area:volume ratios
- use simple compound measures such as rate
- carry out rate calculations
- plot, draw and interpret appropriate graphs.

Health, disease and the development of medicines

Health and disease

- define health and disease.

Infectious diseases

- recall that bacteria, viruses, protoctista and fungi can cause infectious disease in animals and plants
- show understanding of how infectious diseases are spread in animals and plants: (to include a minimum of one common infection, one plant disease, and sexually transmitted infections in humans including HIV/AIDS)
- explain how the spread of infectious diseases may be reduced or prevented in animals and plants. To include a minimum of one common infection, one plant disease and sexually transmitted infections in humans including HIV/AIDS
- **recognise and explain the difficulties of controlling infections in plants**
- describe the non-specific defence of the human body against pathogens
- describe the role of the specific immune system of the human body in defence against disease.

Treating, curing and preventing disease

- describe the use of vaccines and medicines in the prevention and treatment of disease
- outline the discovery and development of new medicines, including preclinical and clinical testing.

Non-communicable diseases

- explain that many human diseases are not caused by infectious agents and are multifactorial. These include heart disease, cancers and nutritional diseases
- describe and evaluate some different treatments for cardiovascular disease
- evaluate the effect of exercise, diet and smoking on the incidence of cardiovascular disease.

Use of mathematics

- translate information between graphical and numerical forms
- plot and draw different types of appropriate graphs selecting appropriate scales

for the axes

- calculate cross-sectional areas of bacterial cultures and clear agar jelly using πr^2.

Coordination and control

Nervous coordination and control in humans

- describe the structure of the brain, spinal cord, sensory and motor neurones and sensory receptors
- relate the structure of the brain, spinal cord, sensory and motor neurones and sensory receptors to their functions
- explain how the structure of a reflex arc is related to its function.
- **recognise the structure of the main parts of the eye and relate these structures to their functions in vision**
- **describe common defects of the eye and discuss how some of these problems may be overcome**
- **recognise the difficulties of investigating brain function and of repairing the brain and other parts of the nervous system**.

Hormonal coordination and control in humans

- [describe the principles of hormonal coordination and control by the human endocrine system]
- **recognise some of the main organs of the human endocrine system exemplified by the pituitary gland, thyroid gland, pancreas, adrenal glands, ovaries and testes**
- **summarise the roles of thyroxine, adrenaline,** [explain how] insulin and glucagon [control blood sugar levels] in the body
- compare type 1 and type 2 diabetes and explain how they can be treated.

Hormones in human reproduction

- explain the function of hormones in human reproduction, including the control of the menstrual cycle involving FSH, LH, oestrogen and progesterone
- evaluate different methods of contraception
- explain the use of hormones in modern reproductive technologies to treat infertility.

Plant hormones

- explain the importance of auxins, **gibberellins and ethene** in the control and coordination of plant growth and development

- explain that some plant hormones are transported around the plant in the xylem and phloem
- describe some of the different ways in which people use plant hormones to control plant growth.

Use of mathematics

- extract and interpret data from graphs, charts and tables.

Homeostasis

- explain the importance of maintaining a constant internal environment
- explain the importance of removing the waste products of metabolism including carbon dioxide and urea
- [summarise the roles of the skin, the lungs and the kidneys in homeostasis and excretion]
- **explain the function of the skin in the control of body temperature**
- **predict the effect on cells of osmotic changes in body fluids**
- **describe the function of the kidneys in maintaining the water balance of the body explaining the effect of ADH on the permeability of the kidney tubules**
- **explain the response of the body to different temperature and osmotic challenges**.

Use of mathematics

- translate information between numerical and graphical forms
- extract and interpret information from charts, graphs and tables.

Photosynthesis

Importance of photosynthesis

- state that light is needed for photosynthesis, recall the main reactants and products of photosynthesis and recognise photosynthesis as an endothermic reaction
- describe plants and algae as the main producers of food for life on Earth.

Factors affecting photosynthesis

- demonstrate the effect of light intensity on the rate of photosynthesis

- **predict the effect of temperature and carbon dioxide concentration on the rate of photosynthesis**
- evaluate the effect of long term changes in carbon dioxide levels, light intensity and temperature on photosynthesis.

Use of mathematics

- understand and use simple compound measures such as the rate of a reaction
- translate information between graphical and numerical form
- plot and draw appropriate graphs, selecting appropriate scales for axes
- **understand and use inverse proportion, the inverse square law and light intensity in the context of factors affecting photosynthesis**
- extract and interpret information from graphs, charts and tables.

Material cycles

The principle of material cycling

- recognise that many different materials cycle through the abiotic and biotic components of an ecosystem.

The decomposers

- recognise that many microorganisms are decomposers
- explain the role of microorganisms in the cycling of materials through an ecosystem
- **explain the importance of nitrogen-fixing bacteria in root nodules**
- describe the carbon cycle and explain its importance
- **predict the effect of factors such as temperature and water content on rate of decomposition**
- analyse data on the changing distribution of organisms in response to climate changes
- **evaluate the evidence for the impact of changes in atmospheric carbon dioxide levels on the distribution of living organisms**.

Use of mathematics

- calculate the rate changes in compost breakdown
- calculate the percentage of mass change.

Ecosystems

Levels of organisation within an ecosystem

- recognise the different levels of organisation from individual organisms to the whole ecosystem
- the components of an ecosystem
- describe abiotic and biotic factors that affect communities
- explain the importance of interdependence and competition in a community.

Pyramids of biomass and transfer through trophic levels

- recognise trophic levels
- describe pyramids of biomass and deduce the sources of the loss of biomass between them
- **calculate the efficiency of energy transfers between trophic levels**.

Biodiversity

- carry out an investigation into the distribution and abundance of organisms in an ecosystem and determine their numbers in a given area
- explain what is meant by biodiversity and discuss the challenges
- recognise both positive and negative human interactions with ecosystems and their impact on biodiversity
- discuss benefits of maintaining local and global biodiversity.

Some of the biological challenges of increasing food yields using fewer resources

- **state reasons for the increase in global human population**
- **discuss the relationship between this increase and changing birth and death rates**
- **describe possible biological solutions, including those using new biotechnologies, to the problems of the growing human population**.

<u>Use of mathematics</u>

- calculation arithmetic means
- understand and use percentiles
- plot and draw appropriate graphs, selecting appropriate scales for the axes
- extract and interpret information from charts, graphs and tables.

Inheritance, variation and evolution

Reproduction

- **recognise the advantages and disadvantages of asexual and sexual reproduction in animals and plants**.

The genome

- describe DNA as a polymer made up of two strands forming a double helix
- recall that DNA is made from four types of nucleotides; **each nucleotide consists of a common sugar and phosphate group with one of four different bases attached to the sugar**
- describe the genome as the entire DNA of an organism
- explain that the genome interacts extensively with the environment to influence the development of the phenotype
- explain the following terms: chromosome, gene, variant, dominant, recessive, homozygous, heterozygous, genotype and phenotype
- discuss the potential importance for medicine of our increasing understanding of the human genome.

Gene expression

- **recognise how the genome influences the development of an organism, to include a simple treatment of protein synthesis**
- explain monogenic inheritance
- predict the results of monogenic crosses
- recognise that most phenotypic features are the result of multifactorial rather than monogenic inheritance
- describe sex determination in humans
- **describe the work of Mendel in discovering the basis of genetics and recognise the difficulties of understanding inheritance before the mechanism was discovered**.

Variation and evolution

- state that there is usually extensive genetic variation within a population of a species
- explain that most genetic variants have no effect on the phenotype, some variants contribute to the phenotype and, rarely, a single variant will control an aspect of the phenotype
- explain that all genetic variants arise originally through mutations

- describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species
- describe how evolution occurs through natural selection of variants best suited to their environment
- evaluate the evidence for evolution to include fossils and antibiotic resistance in bacteria
- describe the work of Darwin and Wallace in the development of the theory of evolution by natural selection
- explain the impact of these ideas on modern biology.

Selective breeding and genetic engineering

- describe the impact of selective breeding on food plants and domesticated animals
- describe the main stages of the process of genetic engineering
- explain some of the possible benefits of using genetic engineering in modern agriculture and medicine
- recognise some of the practical and ethical issues of using genetic engineering in modern agriculture and medicine.

Use of mathematics

- understand and use direct proportions and ratios in genetic crosses
- understand and use the concept of probability in predicting the outcome of genetic crosses
- extract and interpret information from charts, graphs and tables.

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.

This content sets out the full range of content for GCSE Chemistry and the chemistry component of the combined double award in science. Awarding organisations may however use any flexibility to increase depth, breadth or context within the specified topics or to consolidate teaching of the subject content.

Statements below in **bold text** apply only to GCSE specifications in single award chemistry. Statements in [square brackets] apply only to specifications in combined double award science.

Scope of study

GCSE specifications should require students to:

Atomic structure and the Periodic Table

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

- describe how and why the atomic model has changed over time
- 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
- recall relative charges and approximate relative masses of protons, neutrons and electrons
- calculate numbers of protons, neutrons and electrons in atoms and ions, given proton number and mass number of isotopes.

The principles underpinning the modern Periodic Table

- 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
- relate the reactions of elements to the arrangement of electrons in their atoms and hence to their atomic number.

Properties and trends in properties of elements in Groups 1, 7 and 0.

- recall the simple properties of Groups 1, 7 and 0

- correlate observed trends in simple properties of Groups 1,7 and 0 with the electronic structure of the atoms and predict properties from given trends.

Properties of transition metals

- **state the general properties of transition metals (melting point, density, reactivity, formation of coloured ions with different charges and uses as catalysts) and exemplify these by reference to a small number of transition metals.**

The prediction of chemical properties, reactivity and type of reaction from position in the Periodic Table

- show understanding that the Periodic Table allows predictions to be made about how elements might react
- predict reactions and reactivity of elements from their positions in the Periodic Table.

Physical and chemical properties of metals related to their atomic structure and position in Periodic Table

- distinguish between metals and non-metals on the basis of their characteristic physical and chemical properties
- relate the atomic structure of metals and non-metals to their position in the Periodic Table.

Structure, bonding and the properties of matter

Different kinds of chemical bonds: ionic, covalent and metallic bonding

- distinguish between the nature and arrangement of chemical bonds in ionic compounds, simple molecules, and giant molecular structures and polymers
- explain chemical bonding in terms of electrostatic forces and describe the transfer or sharing of electrons
- appreciate the limitations of dot and cross diagrams as representations.

Chemical bonds and their arrangement in relation to properties of materials, ionic compounds, molecules, giant molecules, and metals

- explain how the different types of bonds, their strengths in comparison with intermolecular forces, and the ways they are arranged are related to the properties of the materials.

States of matter and change of state in terms of particle kinetics, energy transfers and the relative strength of chemical bonds and intermolecular forces

- 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
- explain the limitations of the particle model when particles are represented by inelastic spheres
- 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
- use data to predict states of substances at given conditions.

Bulk and surface properties of matter including nanoparticles

- **show understanding of the principles of molecular recognition using a simple ‘lock and key’ model**
- **appreciate that bulk properties of matter result from macro structures of atoms, but the atoms themselves do not have these properties**
- **write ‘nano’ in standard mathematical form**
- **relate ‘nano’ to typical dimensions of atoms and molecules**
- **relate surface area to volume for different-sized particles and describe how this affects properties**
- **relate the properties of nanoparticulate materials to their uses**
- **consider the possible risks associated with some nanoparticulate materials.**

Allotropy of carbon

- explain the properties of diamond, graphite, fullerenes and graphene in terms of their structures and bonding.

Use of mathematics

- estimate size and scale of atoms and nanoparticles
- translate information between diagrammatic and numerical forms
- represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures e.g. allotropes of carbon
- interpret, order and calculate with numbers written in standard form when dealing with nanoparticles
- use ratios when considering relative sizes and surface area to volume comparisons.

Chemical changes

Chemical symbols and formulae

- use chemical symbols to write the formulae of elements and binary compounds, both covalent and with monoatomic and polyatomic ions
- deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa.

Chemical equations, including representations using simple half equations and ionic equations and state symbols

- use the names and symbols of common elements and compounds to write formulae and balanced chemical equations and half equations
- use the formulae of common ions to deduce the formula of a compound and write balanced ionic equations
- describe the physical states of products and reactants using state symbols (s, l, g and aq).

Reactions of acids

- recall that acids react with metals and carbonates and write equations predicting products from given reactants.

Definitions with reference to hydrogen and hydroxide ions

- recall that acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions.

Neutralisation reactions

- describe neutralisation as acid reacting with alkali to form a salt plus water
- recognise that aqueous neutralisation reactions can be generalised to hydrogen ions reacting with hydroxide ions to form water.

Dilute and concentrated, weak and strong acids

- use and explain the terms dilute and concentrated (amount of substance) and weak and strong (degree of ionisation) in relation to acids.

The pH scale

- show the simple connection between hydrogen ion concentration and pH
- 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).

Redox reactions (oxidation and reduction)

- explain oxidation and reduction in terms of loss or gain of oxygen and loss or gain of electrons.

Displacement reactions as redox reactions

- recognise that displacement reactions are examples of redox reactions and identify which species are oxidised and which are reduced.

The reactivity series of metals as the tendency of a metal to form its positive ion

- relate the reactivity of metals with water or dilute acids to the tendency of the metal to form its positive ion
- deduce an order of reactivity of metals from experimental results.

Electrolysis of various molten ionic liquids and aqueous ionic solutions

- recall that metals (or hydrogen) are formed at the cathode and non-metals are formed at the anode in electrolysis using inert electrodes
- predict the products of electrolysis of binary ionic compounds in the molten state
- describe the origin of competing reactions in the electrolysis of aqueous solutions of ionic compounds.

Reactions at the electrodes

- describe electrolysis in terms of the ions present and reactions at the electrodes.

<u>Use of mathematics</u>

- arithmetic computation and ratio when determining empirical formulae, balancing equations and considering pH.

Energy changes in chemistry

Exothermic and endothermic reactions, including reaction profiles

- distinguish between endothermic and exothermic reactions on the basis of the temperature change of the surroundings
- draw and label a reaction profile for an exothermic and an endothermic reaction
- recognise activation energy from a reaction profile as the total energy needed to break bonds in reactant molecules
- calculate energy changes (ΔH) in a chemical reaction by considering bond making and bond breaking energies in kJ.

Carbon compounds as fuels

- recall that crude oil is a main source of hydrocarbons as fuel
- appreciate that crude oil is a finite resource.

Chemical cells and fuel cells

- recall that a chemical cell produces an electrical voltage until the reactants are used up
- compare the advantages and disadvantages of hydrogen/oxygen and other fuel cells for given uses.

<u>Uses of mathematics</u>

- arithmetic computation when calculating energy changes
- interpretation of charts and graphs when dealing with reaction profiles.

The rate and extent of chemical change

Factors that influence the rate of reaction, including catalysts

- suggest practical methods for determining the rate of a given reaction
- interpret rate of reaction graphs
- describe the effect of changes in temperature, concentration, pressure, and surface area on rate of reaction
- explain the effects of changes in temperature, concentration and pressure in terms of frequency and energy of collision between particles
- explain the effects of changes in the size of the pieces of a reacting solid in terms of surface area to volume ratio

- describe the characteristics of catalysts and their effect on rates of reaction
- identify catalysts in reactions
- explain catalytic action in terms of activation energy
- recall that enzymes act as catalysts in biological systems.

Reversible reactions and the concept of dynamic equilibrium

- recognise that some reactions may be readily reversed by altering the reaction conditions and that dynamic equilibrium occurs when the rates of forward and reverse reactions are equal
- predict and explain the effect of changing reaction conditions (concentration, temperature and pressure) on equilibrium position.

Uses of mathematics

- arithmetic computation, ratio when measuring rates of reaction
- drawing and interpreting appropriate graphs from data to determine rate of reaction
- determining gradients of graphs as a measure of rate of change to determine rate
- proportionality when comparing factors affecting rate of reaction.

Organic chemistry

Homologous series, including alkanes [and], alkenes ***and alcohols***

- recognise functional groups and identify members of the same homologous series
- name and draw the structural formulae, using fully displayed formulae, of the first four members of the straight chain alkanes, alkenes **and alcohols**.

Simple reactions of alkanes [and], alkenes ***and alcohols***

- predict the formulae and structures of products of reactions (combustion, addition across a double bond **and oxidation of alcohols to carboxylic acids**) of other members of these homologous series.

Addition ***and condensation polymerisation***

- explain the basic principles of addition polymerisation and condensation polymerisation by reference to the minimum number of functional groups within a

monomer, number of repeating units in the polymer, and simultaneous formation or otherwise of a small molecule
- deduce the structure of an addition polymer from a simple alkene monomer and vice versa.

Naturally-occurring and synthetic polymers, including DNA

- appreciate that DNA is a polymer made from four types of monomer called nucleotides and that each nucleotide consists of a common sugar and phosphate group with one of four different bases attached to each sugar
- appreciate that a knowledge of organic chemistry is necessary to understand the chemical properties of the vast array of naturally occurring and synthetic materials by reference to the generality of reactions of functional groups and the ability of carbon to form chains, rings and helices.

Chemical analysis

Pure and impure substances

- know what is meant by the purity of a substance, distinguishing between the scientific and everyday use of the term 'pure'.

Separation techniques for mixtures of substances, including filtration, crystallisation, simple distillation, fractional distillation, and chromatography in a variety of phases

- describe, explain and exemplify the processes of filtration, crystallisation, simple distillation, and fractional distillation
- recall that chromatography involves a stationary and a mobile phase and that separation depends on the distribution between the phases
- interpret chromatograms, including measuring Rf values
- suggest suitable purification techniques given information about the substances involved.

Measurement of purity of substances

- distinguish pure from impure substances from melting point data
- suggest chromatographic methods for distinguishing pure from impure substances.

Identification of ions and gases by chemical and spectroscopic means

- **describe tests to identify selected gases, including oxygen, hydrogen,**

carbon dioxide and chlorine, aqueous cations and aqueous anions

- **identify species from test results**
- **interpret flame tests for metal ions, including the ions of lithium, sodium, potassium, calcium and copper**
- **describe the advantages of instrumental methods of analysis (sensitivity, accuracy and speed)**
- **interpret an instrumental result given appropriate data in chart or tabular form, accompanied by a reference set in the same form.**

Conservation of mass

- apply the law of conservation of mass
- account for observed changes in mass in non-enclosed systems during a chemical reaction and explain them using the particle model.

The quantitative interpretation of balanced equations

- calculate relative formula masses of species separately and in a balanced chemical equation.

Use of the mole in relation to masses of pure substances, ***volumes of gases and concentrations of solutions***

- understand and use the definitions of the Avogadro constant (in standard form) and of the mole
- relate the mass of a given substance to the amount of that substance in moles and vice versa
- **use the molar gas volume at room temperature and pressure (assumed to be 24 dm^3) to relate molar amounts of gases to their volumes and vice versa, and to calculate volumes of gases involved in reactions**
- **relate the mass of a solute and the volume of the solution to the concentration of the solution**
- determine the stoichiometry of an equation from the masses of reactants and products including the effect of a limiting quantity of a reactant

  use a balanced equation to calculate masses of reactants or products.

Principles for determining the concentrations of solutions

- **relate the concentration of a solution in mol/dm^3 to the mass of a solute and the volume of solution**
- **relate the volume of a solution of known concentration of a substance**

required to react completely with a given volume of a solution of another substance of known concentration.

Use of mathematics

- arithmetic computation, ratio, percentage and multistep calculations permeates quantitative chemistry
- calculations with numbers written in standard form when using the Avagadro constant
- change the subject of a mathematical equation
- provide answers to an appropriate number of significant figures
- convert units where appropriate particularly from mass to moles
- interpret charts, particularly in spectroscopy.

Chemical and allied industries

The comparison of yield and atom economy of chemical reactions

- **calculate theoretical amount of product from a given amount of reactant**
- **from the actual yield of a reaction, calculate the percentage yield of a reaction product**
- **define the atom economy of a reaction**
- **calculate the atom economy of a reaction to form a desired product from the balanced equation**
- **select and justify a choice of reaction pathway to produce a specified product given appropriate data such as atom economy (if not calculated), yield, rate, equilibrium position.**

Fractional distillation of crude oil and cracking

- describe and explain the separation of crude oil by fractional distillation and the production of more useful materials by two methods of cracking.

Carbon compounds as feedstock for the chemical industry

- recall that crude oil is a main source of hydrocarbons as feedstock for the chemical industry.

Different methods of extracting and purifying metals with reference to the reactivity series and the position of carbon within it

- use the position of carbon in the reactivity series to explain the principles of industrial processes used to extract metals, including extraction of a non-ferrous metal
- explain why and how electrolysis is used to extract some metals from their ores
- evaluate alternative methods of extraction, such as bioleaching.

Production, properties and uses of alloys

- **relate the composition of some important alloys to their properties and uses.**

Causes of corrosion and their mitigation

- **identify the conditions for corrosion and explain how mitigation is achieved by creating a physical barrier to oxygen and water or by sacrificial protection.**

The balance between equilibrium position and rate in industrial processes

- explain the trade-off between rate of production of a desired product and position of equilibrium in some industrially important processes
- interpret graphs of reaction conditions versus rate
- relate the commercially used conditions for an industrial process to the availability and cost of raw materials and energy supplies, control of equilibrium position and rate.

Agricultural productivity and the use of nitrogen, phosphorus and potassium-based fertilisers

- **recognise the importance of the Haber process in agricultural production**
- **show understanding of the importance of nitrogen, phosphorus and potassium compounds in agricultural production**
- **recognise that the industrial production of fertilisers requires several integrated processes and a variety of raw materials**
- **synthesise an ammonia-based fertiliser.**

Ceramics, polymers and composites

- compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals
- select appropriate materials given details of usage required, relating uses to properties.

The efficacy of recycling

- describe the basic principles in carrying out a life-cycle assessment of a material or product
- interpret data from a life cycle assessment of a material or product
- describe a process where a material or product is recycled for a different use, and why this is viable
- appreciate why some materials or products cannot be recycled and recycling others is not economically viable.

<u>Use of mathematics</u>

- **arithmetic computation when calculating yields and atom economy.**

Earth and atmospheric science

The composition and evolution of the atmosphere since its formation

- show understanding of the evidence for how it is thought the atmosphere was originally formed and how it has changed over time.

Carbon dioxide and methane as greenhouse gases

- understand the greenhouse effect in terms of the interaction of radiation with matter
- recognise the causes of change in Earth's climate over geological timescales before the industrial period
- describe and analyse the evidence for additional anthropogenic causes of climate change, including changes in the Earth's orbit, changes in the atmosphere, the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels, and show an appreciation of the uncertainties in the evidence base
- describe the potential effects of climate change.

Carbon capture and storage

- show understanding of the principles of carbon capture and storage to reduce atmospheric levels of carbon dioxide
- compare and contrast industrial processes for carbon capture and storage with the carbon cycle and naturally occurring processes in the oceans, including

consideration of scale and environmental implications.

Common atmospheric pollutants and their sources

- recognise the major sources of carbon monoxide, sulfur dioxide, oxides of nitrogen and particulates in the atmosphere and the problems caused by increased amounts of these.

The Earth's water resources and obtaining potable water

- describe the effects of human activity and increased population on the availability of potable water
- describe the principal methods for making water potable in terms of the separation techniques used, including ease of treatment of waste, ground and salt water.

Use of mathematics

- extract and interpret information from charts graphs and tables
- use orders of magnitude to evaluate the significance of data.

Physics

Students should be helped to appreciate the achievements of physics in showing how the complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas – representing such features as equilibrium, differences driving change, forces and fields, and transmission by waves – which are inter-linked and are of universal application.

This content sets out the full range of content for GCSE physics and the physics component of the combined double award in science. Awarding organisations may however use any flexibility to increase depth, breadth or context within the specified topics or to consolidate teaching of the subject content.

Statements below in **bold text** apply only to GCSE specifications in single award physics. Statements in [square brackets] apply only to specifications in combined double award science.

Scope of study

GCSE specifications should require students to:

Energy

Mechanical, thermal and electrical changes transfer energy between sources

- identify and quantify the different ways that the energy of a system can be changed through work done by forces, in electrical equipment, or in heating, and describe how each of these may be measured
- relate everyday examples of changes to systems to descriptions and explanations of the physical processes by which changes come about, including heating by conduction and radiation and the movement of hot fluids (convection).

Conservation of energy

- explain, with examples, that there is no net change to the total energy of a closed system.

The ways in which energy is associated with moving, vibrating, raised or heated objects, reactive chemicals and unstable nuclei

- analyse a system before and after a change and identify the ways in which energy in the system is re-distributed in: movement; vibration; stretching or compression; motion of particles; temperature changes by heating or by working or by an electrical appliance; burning of fuels (in oxygen) to heat objects or to do work in moving objects; changes in chemical composition; changes in position (of a mass in a gravitational field or of a charge in an electrical field).

Calculating amounts of energy including likely or possible values of quantities after a change in a system; dissipation

- carry out before-and-after analyses and calculations of energy values for such changes
- explain that when energy is transferred by heating, the energy will inevitably end up being stored in a less useful, often unrecoverable, way **after the process – because it is, in some sense, less concentrated, and similarly** explain that mechanical processes become wasteful when they cause a rise in temperature so dissipating energy in heating the surroundings, or when they do electrical work against resistance of connecting wires
- relate dissipation to other areas of the sciences (osmosis, diffusion, pressure differences) in which difference causes change and, as a result, the difference is reduced.

Waste and efficiency

- explain how these examples of waste can be reduced by lubrication, insulation, and low resistance wires
- explain the meaning of energy efficiency, calculate it for any energy transfer, and describe ways to increase efficiency.

National and global energy sources

- list and describe the main energy sources available for use on Earth (including fossil fuels, nuclear fuel, bio-fuel, wind, the tides and the Sun) and distinguish between renewable and non-renewable sources.

<u>Uses of mathematics</u>

- calculate the energy changes associated with changes in a system, selecting the relevant equations for mechanical, electrical, and thermal processes, and to the burning of fuels, to put into quantitative form and on a common scale the overall redistribution of energy in the system.

Motion

Speed, velocity and acceleration

- explain the vector-scalar distinction as it applies to displacement, velocity and speed
- estimate the speeds encountered in everyday experience, both for natural phenomena (wind, sound, light) and transportation systems; and the magnitudes of everyday accelerations, including the acceleration in free fall
- **explain that motion in a circle involves constant speed but changing velocity (qualitative only).**

relative motion

- relate linear motion as observed from one moving vehicle to its observation from another moving relative to the first; **relate this to our other relative motions, such as the earth's relative to the Sun**.

distance-time and velocity-time graphs

- make and interpret measurements of distances, times, speeds and accelerations, and represent these in graphical form
- **explain the implications of human reaction times in relation to safety in transport**.

Uses of mathematics

- make calculations using ratios and proportional reasoning to convert units and to compute rates
- represent changes and differences using appropriate distance-time, velocity-time and acceleration-time graphs, and interpret lines, slopes and enclosed areas in such graphs
- apply formulae relating distance, time and speed, for uniform motion, and for motion with uniform acceleration, and calculate average speed for non-uniform motion.

Forces

Contact forces, stretching, and friction

- identify forces between solid objects which stretch, compress, bend, and turn, or affect movement
- explain that frictional forces affect movement and depend on the properties of the surfaces involved.

Force as a vector

- recognise that forces have a well-defined direction and are vectors
- *measurements and the Newton*
- relate the Newton as the unit of force to the units of inertial mass and of acceleration.

Moments and rotational forces; levers and gears

- recognise forces that cause rotation
- define the moment of such forces and calculate their values
- explain how levers and gears transmit the effects of linear **and rotational forces**.

Work done and energy transfer

- relate the work done by a force, as the product of the force and the distance moved along its line of action, to the transfer of energy and relate Newton-metres to joules.

Pressure

- describe observations showing that fluids exert forces in all directions: explain that pressure, the force per unit area exerted by, or on, any fluid, acts normal to any surface
- **explain why the work done in the compression or expansion of gases is the product of the pressure and the change in volume**.

Non-contact forces, magnetic, electrical and gravity forces and fields

- give examples of forces which act without contact across an empty space, linking these to the gravity, electric and magnetic fields involved.

Equilibrium with balanced forces

- explain the concept of equilibrium and identify, for equilibrium situations, the forces which balance one another.

Uses of mathematics

- calculate relevant moments, pressures and energy transfers; **intra-convert Newton-metres with joules**
- use vector diagrams to illustrate resolution of forces, a net force, and equilibrium situations (qualitative only).

Forces and motion

Acceleration; uniform velocity in absence of net force

- recall Newton's First Law and relate it to observations showing that forces can change direction of motion as well as its speed; identify and distinguish between these for forces which alter motion in everyday experience.

Inertial mass

- explain that inertia is a measure of how difficult it is to change the velocity of an object (including from rest)
- recall Newton's Second Law and explain its status as the definition of inertial mass.

Collisions and safety; and the three Newtonian laws of motion

- explain that force is rate of momentum change and explain the dangers caused by large decelerations and the forces involved
- **recall and apply Newton's Third Law both to equilibrium situations and to collision interactions and relate it to the conservation of momentum in collisions.**

Gravitational and inertial mass

- **explain that weight is an effect of gravity which can vary with the gravitational field strength g (measured in N/kg) and recognise and predict phenomena that depend on weight and on inertial mass and distinguish between the two.**

Uses of mathematics

- apply formulae relating force, mass, velocity, and acceleration to explore how changes involved are inter-related
- apply equations about conservation in collisions.

Waves in matter

Waves in air, fluids and solids; transverse and longitudinal; frequency, wavelength and velocity

- describe wave motion in terms of the wavelength and frequency of waves in water, explaining how these may be measured, that they are transverse, that it is the wave and not the water itself that travels; explain the relationship between velocity, frequency and wavelength
- compare water waves and sound waves and explain the difference between transverse and longitudinal waves
- describe how to measure the velocity of sound in air.

Superposition, reflection, absorption and resonance

- describe and explain superposition in water waves and the effects of reflection, transmission, and absorption of waves at material interfaces
- **describe examples of wave vibration in solid materials, such as drum-skins, violin strings, explain that these objects may produce, or be excited by, specific frequencies, and that this effect is called resonance**.

The ear: audible and inaudible frequencies

- explain the links between the terms loudness and amplitude, and pitch and frequency for audible waves
- explain processes which convert wave disturbances between sound waves and vibrations in solids, why such processes only work over a limited frequency range, and the relevance of this to human audition.

Exploring structures in earth and oceans; and energy transfer by waves

- **explain, in qualitative terms, how the differences in velocity, absorption and reflection between different types of waves in solids and liquids can be used to for detection and for exploration of structures which are hidden from direct observation, notably in the Earth's core and in the oceans**.

Uses of mathematics

- apply formulae relating velocity, frequency and wavelength, and predict changes in transmission of sound waves from one medium to another.

Light as rays and as waves

Reflection specular and diffuse

- use the ray model to show how light travels and to illustrate specular reflection and the apparent position of images in plane mirrors
- explain the difference between specular and diffuse reflection.

Refraction and lens action (qualitative)

- use the ray model to illustrate refraction and explain the apparent displacement of an image in a refracting substance (qualitative only): **similarly explain the effects of different types of lens in producing real and apparent images (qualitative only)**.

Velocity in vacuum and in matter

- recall that light can also be understood as a wave motion and explain and apply the relationship between frequency, wavelength and velocity
- recall that wavelength and frequency vary across the visible spectrum, explain how this relates to the overall constant velocity in a vacuum, although it can be lower by different amounts in different media.

Colour and frequency; differential effects in transmission, absorption and diffuse reflection

- **identify common materials in which light is entirely or partially absorbed, and explain how colour is related to differential absorption, transmission and reflection**.

Uses of mathematics

- construct two-dimensional ray diagrams to illustrate specular reflection, to locate the position of an image in a plane mirror, **and to illustrate the action of convex and concave lenses**
- apply formulae relating velocity, frequency and wavelength.

Electromagnetic waves

Frequency range of spectrum, from gamma rays to radio waves

- recall that electromagnetic waves are transverse, are transmitted through space where all have the same velocity, and that they transfer energy from source to absorber
- describe the main groupings of the spectrum – radio, microwave, infra-red, visible (red to violet) ultra-violet, X-rays and gamma-rays, that these range from long to short wavelengths and from low to high frequencies, and that our eyes can only detect a limited range.

Electromagnetic radiation and matter

- recall that different substances may absorb, transmit, refract, or reflect these waves, each substance in ways that vary with wavelength; explain how some differences are related to differences in the velocity of the waves in different substances
- **explain that all bodies emit radiation, that the intensity and wavelength distribution of any emission depends on their temperature and how this relates to the balance between incoming radiation absorbed and radiation emitted which affects the temperature of the earth**
- **give examples of some practical uses of electromagnetic waves in each of the main groups of wavelength, and knows that some waves can have hazardous effects, notably on human bodily tissues**.

Applications for generation and detection

- recall that radio waves can be produced by or can themselves induce oscillations in electrical circuits, and that changes in atoms and nuclei can also generate and absorb radiations over a wide frequency range.

Amplitude and frequency modulation to transfer information

- **explain the concept of modulation and how information can be transmitted by waves through variations in amplitude or frequency, and that each of these is used in its optimum frequency range.**

Uses of mathematics

- apply the relationships between frequency and wavelength across the electromagnetic spectrum.

Electricity

Current, potential difference

- explain that for a current to flow, a source of e.m.f. and a closed circuit are needed
- distinguish between the e.m.f. of a battery or other source and the potential difference between two points in a circuit
- make d.c. electric circuits; and represent them with the conventions of positive and negative terminals, and the symbols that represent cells, batteries, switches, and resistors in circuit diagrams
- recall that the current is a flow of charge and explain that a current has the same value at any point in a single closed loop, and how the quantity of charge flowing is related to current and time.

Resistance

- explain that the equation R = V/I defines resistance, measured in ohms, that for some resistors the value of R remains constant but that in others it can change as the current changes; design and use circuits to explore such changes – including for lamps, diodes, thermistors and LDRs.

In-series and parallel circuits

- distinguish between series and parallel circuits, and explain why, if two resistors are in series the net resistance is increased, whereas with two in parallel the net resistance is decreased
- calculate the currents, potential differences and resistances in series circuits, and design, construct, test and describe such circuits.

D.C. and A.C.

- recall that the domestic supply is a.c., at 50Hz. and about 230 volts in the UK, explain the difference between direct and alternating voltages, **and discuss the advantages of using a higher or a lower voltage**
- explain how and why domestic circuits use a ring main.

Domestic uses and safety

- explain the difference between the live and the neutral mains input wires, **that the live wire is dangerous even when any switch that completes is open, and that switches should be connected across the live wire input side of any equipment**

- explain the function of an earth wire and of fuses or circuit breakers in ensuring safety.

Energy transfer and conversion

- calculate the power, transferred in any circuit device and relate this to the e.m.f. applied and the circuit resistance, and to the energy changes over a given time
- **describe the ways in which different domestic devices transform electrical energy into the energy of motors or of heating devices**.

Static electricity – forces and electric fields

- describe the production of static electricity, and sparking, by rubbing surfaces, and evidence that charged objects exert forces of attraction or repulsion on one another when not in contact and that these forces get stronger as the distance between them decreases
- **explain how the production of sparks shows that similar forces exist between the positive and negative poles of a d.c. source**
- **explain these effects in terms of the transfer of electrons between substances giving them charges of opposite sign, that opposite charges attract and that charges of the same sign will repel**.

<u>Uses of mathematics</u>

- select and use the equations relating potential difference , current, quantity of charge, resistance, power, energy, and time, and solve problems for circuits which include resistors in series using the concept of equivalent resistance
- use graphs to explore whether circuit elements are linear or non-linear and relate the curves produced to their function and properties.

Magnetism and Electromagnetism

Permanent and induced magnetism

- describe the attraction and repulsion between unlike and like poles for permanent magnets and explain the difference between permanent and induced magnets.

Magnetic forces and fields and the Earth's field

- describe the characteristics of the magnetic field of a magnet, showing how these effects change direction from one point to another, **and explain how this links to the forces magnets exert on each other without actual contact**

- relate the characteristics of a magnetic compass to evidence that the core of the Earth must be magnetic.

Magnetic effects of currents

- explain how to show that a current can create a magnetic effect and describe the directions of the magnetic field around a conducting wire
- recall that the size of the field depends on the current and the distance from the conductor, and explain how solenoid arrangements can enhance the magnetic effect
- describe how a magnet and a current-carrying conductor exert forces on one another which depend on their relative orientation and on the direction of the current.

Motors; induction and dynamos

- explain how electric motors are designed to use this effect, with examples of the use of such motors in domestic appliances
- recall that a change in the magnetic field around a conductor can give rise to an induced e.m.f. across its ends, which could drive a current, generating a field that would oppose the original change; hence explain how this effect is used in an alternator to generate a.c., and in a dynamo to generate d.c.
- **explain how the effect of an alternating current in one circuit in inducing an e.m.f. in another is used in transformers and how the difference between the potential differences across the two depends on the numbers of turns in each**.

National grid

- **describe how, in the national grid, electrical power is transported at high voltages from power stations, and then transformed to lower voltages in each locality for domestic use, and explain how this system is an efficient way to transfer energy.**

Microphones and speakers; oscillating currents in detection and generation of radiation

- explain the action of the microphone in converting the pressure variations in sound waves into variations in e.m.f. in electrical circuits, and the reverse effect as used in loudspeakers and headphones.

Uses of mathematics

- apply the equations linking the potential difference s and numbers of turns in the two coils of a transformer, to the currents and the power transfer involved, and relate these to the advantages of power transmission at high voltages.

Particle model of matter

Changes of state; changes with temperature, physical and chemical changes

- explain that when substances melt, freeze, evaporate, condense or sublimate mass is conserved, but that these physical changes differ from chemical changes because the material recovers its original properties if the change is reversed
- **explain the difference between boiling and evaporation**.

Particle model of solid, liquid and gaseous states, kinetic theory of gases and Brownian motion

- explain the differences in density between the different states of matter in terms of the arrangements and motions of the atoms **or molecules and that the differences in boiling and melting temperatures between different substances are related to the differences in the strengths of their inter-molecular bonds**
- **relate the pressure of a gas to the motion of the molecules**.

Internal energy and energy transfers associated with heating and cooling and with changes of state

- relate energy transfers into and out of a material to changes of state and/or changes in temperature, define the terms specific latent heat and specific heat capacity and distinguish between them.

Uses of mathematics

- apply the relationship between density, mass and volume to changes where mass is conserved
- apply the relationship between change in internal energy of a material and its mass, specific heat capacity and temperature change to calculate the energy change involved.

Forces and matter

Stretching, elastic and inelastic, and compression

- recall that, for springs and elastic objects, forces can cause stretching, explain the difference between elastic and inelastic distortion and calculate the work done in stretching, relating it to stored energy and to its conversion into other forms
- recognise the difference between linear and non-linear relationships between force and extension, and calculate a spring constant in linear cases.

Pressure in fluids; pressure and volume in gases

- recall that gases can be compressed or expanded by pressure changes, that the pressure acts at right angles to any surface, **and explain how random motions of molecules accounts for the pressure; give a qualitative reason to explain why pressure x volume is constant at constant temperature.**

Temperature of a gas related to the motion of its particles

- relate increases in the temperature of a gas to the average kinetic energy of its molecules and explain how this leads to an increase in pressure at constant volume
- explain how doing work on a gas can increase its temperature (e.g. bicycle pump).

The atmosphere and pressure

- relate atmospheric pressure to the gases of our atmosphere and explain how this pressure changes with height.

Atmospheric and underwater pressure; upthrust and floating

- **explain why the pressure in liquids varies with density and depth, and calculate the magnitude of the pressure**
- **explain why an object immersed in a liquid is subject to a net upward force which can affect whether or not it floats or sinks.**

<u>Uses of mathematics</u>

- calculate work done in stretching an object in relation to forces and extensions
- represent graphically results of explorations of stretching, interpret the difference between linear and non-linear relationships, and interpret the slope of any graph
- **relate changes in pressure to changes in volume for a fluid (at constant**

temperature), calculate pressures and relate the forces on different surfaces to the areas of those surfaces

- **calculate the change of pressure with depth in a liquid**.

Atomic structure

Nuclear atom

- describe how and why the atomic model has changed over time
- describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller that of the atom and with almost all of the mass in the nucleus.

Isotopes

- recall that atomic nuclei are composed of both positively charged and neutral particles, that each element has a characteristic positive charge, but that elements can differ in nuclear mass by having different numbers of neutral particles
- relate differences between isotopes to conventional representations of their identities, charges and masses.

Absorption and emission of ionizing radiations and of electrons and nuclear particles

- recall that **in each** atom[s] [can emit] **its electrons are in different states, characterised by different mean distances from the nucleus, and bound to it more or less strongly; hence explain how they can change state with absorption or emission of** electromagnetic radiation and how atoms can become ions by loss of outer, electrons
- recall that some nuclei may emit alpha, beta, or neutral particles and electromagnetic radiation as gamma rays; explain how these emissions may or may not change the mass or the charge of the nucleus, or both.

Half-lives

- **explain that radioactive decay is a random process, the concept of half-life and how the hazards associated with radioactive material differ according to the half-life involved, and to the differences in the penetration properties of alpha-particles, beta-particles and gamma-rays.**

Applications including for detection and imaging and in medicine for therapy

- **give examples of practical use of alpha-particles (e.g. smoke detectors), beta-particles (e.g. thickness monitors), and gamma-rays (sterilization)**

  describe and distinguish between uses of nuclear radiations for exploration of internal organs, and to control or destroy unwanted tissue.

Effects on body tissues and other materials

- **explain why radioactive material, whether external to the body, or ingested, is hazardous because of damage to the tissue cells, and that it can weaken the solid structures of other materials which enclose it in nuclear reactors.**

Nuclear Fission

- recall that some nuclei are unstable and may split, and relate such effects to transfer of energy to other particles and to radiation which might emerge.

Uses of mathematics

- balance equations representing alpha-, beta- or gamma-radiations in terms of the masses, and charges of the atoms involved
- **calculate the net decline, expressed as a ratio, in a radioactive emission after a given number of half-lives**.

Space physics

Gravitational and inertial mass

- recognise and predict phenomena that depend either on weight or on inertial mass, distinguish between the two, and explain why very different objects all fall to earth at the same rate if air resistance low.

Law of gravitational attraction

- explain terms and meaning of the inverse square law, and the link between g and Gm_e/r^2, and why g is both an acceleration and a measure of the strength of the gravity field
- explain how and why both the weight of any body and the value of g differ between the surface of the Earth and the surface of other bodies in space, e.g. the moon.

Solar system; stability of orbital motions; satellites

- **explain the difference between planetary orbits and orbits of meteors**
- **explain for circular orbits how the force of gravity can lead to changing velocity of a planet but unchanged speed, how, for a stable orbit, the radius must change if this speed changes (qualitative only), and relate this association to data on the length of years of different planets and to the orbits of communications satellites around the earth**.

Red-shift; the 'Big Bang' and universal expansion

- explain the red-shift of light from galaxies which are receding (qualitative only), that the change of speed with galaxies' distances is evidence of an expanding universe and hence explain the link between this evidence and the Big Bang model.

Energy of the Sun and fusion; other galaxies

- **recall that fusion in stars involves pairs of hydrogen nuclei forming helium, emitting radiation and increasing the particle kinetic energy; hence explain in qualitative terms, that the balance between the resulting thermal expansion and the constraint of gravity can lead to imploding, stable, or exploding stars**.

<u>Uses of mathematics</u>

- apply formulae relating force, mass, distance, and relevant physical constants, to explore how changes in these are inter related.

Working scientifically

Biology, chemistry, physics and double award combined science

1. Development of scientific thinking	▪ be objective, and have concern for, accuracy, precision, repeatability and reproducibility ▪ understand how scientific methods and theories develop over time ▪ recognise the importance of publishing results and peer review ▪ appreciate the power and limitations of science and consider any ethical issues which may arise ▪ evaluate risks both in practical science and the wider societal context, including perception of risk in relation to data and consequences.
2. Experimental skills and strategies	▪ use scientific theories, models and explanations to develop hypotheses ▪ plan experiments to make observations, test hypotheses or explore phenomena ▪ apply a knowledge of techniques, apparatus, and materials to select those appropriate to the experiment and use them appropriately, having due regard to health and safety considerations ▪ apply a knowledge of sampling techniques to ensure any samples collected are representative of the whole population ▪ make and record observations and measurements using a range of methods ▪ evaluate methods and suggest possible improvements and further investigations.

3. Analysis and evaluation	▪ apply the cycle of collecting, presenting and analysing data, including:
	    ▪ present observations and data using appropriate methods
	    ▪ carry out and represent mathematical and statistical analysis
	    ▪ represent random distributions of results and estimations of uncertainty
	    ▪ interpret observations and data, including identifying patterns and trends, make inferences and draw conclusions

	▪ present reasoned explanations including of data in relation to hypotheses ▪ evaluate data ▪ use an appropriate number of significant figures in calculations ▪ communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations.
4. Units, symbols and nomenclature	▪ use SI units (e.g. kg, g, mg; km, m, mm; kj, j), IUPAC chemical nomenclature ▪ use prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, milli, micro and nano) ▪ interconvert units.

Examples from biology

1. Development of scientific thinking	▪ all quantitative biology ▪ the development of genetics, the theory of evolution ▪ evaluation of methods for treating cardiovascular disease, changing distribution of organisms ▪ reproductive technologies, use of stem cells in medicine, use of the human genome, maintaining biodiversity, sustainable food supplies ▪ impact of genetically engineered organisms ▪ vaccine safety.
2. Experimental skills and strategies	▪ predict the effect of a variety of environmental factors on the rate of water uptake and the rate of photosynthesis by a plant ▪ exercise and cooling curves ▪ microbiology investigations ▪ investigate distribution and/or abundance organisms investigations into respiration or enzyme activity ▪ enzyme investigations.
3. Analysis and evaluation	▪ any experimental report ▪ appropriate use of mean values, determination of outliers etc. ▪ use of standard deviation in group results ▪ recognition of the accuracy of laboratory equipment and

	summation of errors to give the range of a result ▪ spread of infectious diseases in humans and plants ▪ changes in distribution of organisms ▪ reports of investigations and experiments.
4. Units, symbols and nomenclature	▪ size of cells and organelles, rate of growth of microbes ▪ magnification in terms of light and electron microscope.

Examples from chemistry

1. Development of scientific thinking	▪ All quantitative chemistry, e.g. determining the stoichiometry of a reaction ▪ structure of the atom, the Periodic Table ▪ discoveries of fullerenes and graphene ▪ atmospheric science, nanoparticles ▪ use of nanoparticulate materials.
2. Experimental skills and strategies	▪ predict the products of electrolysis ▪ measurement of rates of reaction ▪ preparation of fertilisers ▪ selecting appropriate methods for measuring rates of reaction ▪ measurement of common atmospheric pollutants ▪ identification of ions and gases ▪ comparison of methods for measuring rates of reaction.
3. Analysis and evaluation	▪ any experimental report ▪ appropriate use of mean values, determination of outliers etc ▪ recognition of the accuracy of laboratory equipment and summation of errors to give the range of a result ▪ climate data ▪ patterns and trends in the Periodic Table ▪ consider uncertainties in climate data ▪ relate quantitative answers to the accuracy of the measuring instruments ▪ reports of investigations and experiments.

4. Units, symbols and nomenclature	▪ naming organic compounds ▪ the Avogadro constant, nanoparticles.

Examples from physics

1. Development of scientific thinking	▪ structure of the atom, the Periodic Table ▪ expanding universe and the Big Bang ▪ uses of fission and fusion ▪ risks with the uses of radioactive material.
2. Experimental skills and strategies	▪ test whether resistance is independent of current, or whether spring constant is independent of extension ▪ design a domestic mains circuit based on a single fuse plug to maximise lighting intensity ▪ measure the range and distribution of the walking and running speeds of students in a school class
3. Analysis and evaluation	▪ estimate rates of deceleration of a range of vehicles on urban roads and use these to calculate the forces needed to produce these changes ▪ explore how the current in a d.c. circuit varies with the potential difference across the battery terminals ▪ write a report on an investigation for their parents or for students in another class
4. Units, symbols and nomenclature	▪ convert kilowatt hours to energy in joules ▪ compare the power used to heat a room with that used to carry a heavy box upstairs.

Assessment objectives

	Assessment objectives	Weighting
AO1	**Knowledge with understanding** **Recognise, recall and show understanding of:** ▪ scientific phenomena, patterns, laws, theories and models ▪ how scientific theories develop over time and are tested ▪ scientific vocabulary, terminology, definitions, units and conventions ▪ uses of scientific instrumentation and apparatus ▪ scientific quantities and their determination ▪ everyday and technological applications of science with their personal, social, economic and environmental implications ▪ working safely in a scientific context.	30%
AO2	**Application, analysis, evaluation and problem solving** **The skills and abilities to:** ▪ extract data relevant to a particular context from information presented in verbal, diagrammatic, graphical, symbolic or numerical form ▪ translate data from one form to another ▪ evaluate qualitative and quantitative data, carry out calculations as appropriate, recognise patterns in such data, draw conclusions and formulate hypotheses ▪ explain familiar facts, observations and phenomena in terms of scientific laws, theories and models ▪ present reasoned scientific explanations of unfamiliar facts and phenomena, and unexpected observations ▪ apply a knowledge of sampling techniques to ensure any samples collected are representative of the whole population ▪ apply scientific principles and formulate and justify methods to solve qualitative and quantitative problems ▪ make decisions based on the evaluation of evidence and arguments ▪ communicate scientific observations, ideas, arguments and	50%

	conclusions logically, concisely in verbal, diagrammatic, graphical, numerical and symbolic form ▪ explain everyday and technological applications of science and evaluate associated personal, social, economic and environmental implications ▪ evaluate risks in a wider societal context ▪ recognize that the pursuit of science is subject to practical constraints, theoretical uncertainties and ethical considerations.	
AO3	**Experimental skills and methods amenable to indirect assessment** **The experimental skills and abilities to:** ▪ select or formulate propositions amenable to experimental test ▪ devise procedures and select apparatus and materials suitable for synthesising substances or producing or checking the validity of data, conclusions, generalizations and hypotheses ▪ recognise and explain variability and unreliability in experimental measurements ▪ evaluate quantitative and qualitative data acquired through practical work, the design of experiments and experimental observations, draw conclusions and suggest improvements where appropriate.	10%
AO4	**Experimental skills and methods requiring direct assessment** **The ability to:** ▪ follow instructions accurately ▪ use scientific instrumentation, apparatus and materials appropriately ▪ work with due regard for safety, managing risks ▪ observe, measure and record accurately and systematically ▪ carry out and report on investigations or parts of investigations.	10%

Appendix 1

Equations in physics

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

distance travelled = speed x time

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

final velocity = initial velocity + (acceleration x time)

resultant force = mass (m) x acceleration (a)

momentum = m x velocity

$$\text{force (F)} = \frac{\text{change in momentum}}{\text{time}}$$

weight = m x gravitational field strength (g)

change in gravitational potential energy (E_p) = m x g x change in height

kinetic energy (E_k) =1/2 x m x v^2

work done (W) = F x distance moved in the direction of the force

$$\text{power (P)} = \frac{\text{work done}}{\text{time}}$$

$$\text{efficiency of any device or process} = \frac{\text{work done}}{\text{energy supplied}} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$= \frac{\text{useful power output}}{\text{power input}}$$

force (F) applied to a spring = spring constant (k) x extension

moment of a force = force x perpendicular distance from pivot

$$\text{current (I)} = \frac{\text{charge flow (Q)}}{\text{time}}$$

potential difference (V) = current (I) x resistance (R)

Power (P) = voltage (V) x current (I) = I^2 x R energy transferred = P x time = Q x V

distance = wave speed x time

wave speed = frequency (f) x wavelength (λ)

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

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

change in thermal energy = m x specific heat capacity x change in temperature

thermal energy for a change of state = m x specific latent heat

force on a conductor (at right angles to a magnetic field) carrying a current :

= magnetic field strength (B) x current (I) x length

$$\frac{\text{voltage across primary coil } (V_p)}{\text{voltage across secondary coil } (V_s)} = \frac{\text{number of turns in primary coil } (N_p)}{\text{number of turns in secondary coil } (N_s)}$$

$$\frac{V_p}{V_s} = \frac{\text{current in secondary coil } (I_s)}{\text{current in primary coil } (I_p)}$$

At constant temperature: pressure x volume (of a gas) = constant

pressure due to a column of liquid = height of column x density of liquid x g

$$\text{force due to gravity between two masses} = \frac{\text{gravitational constant (G)} \times m_1 \times m_2}{[\text{distance between centre of masses (r)}]^2}$$

energy = m x [speed of light in a vacuum (c)]^2

Appendix 2

SI units in science

The International System of Units (Système International d'Unités), which is abbreviated SI, is a coherent system of seven base units, two supplementary units, and an unlimited number of derived units (eighteen of which have special names).

Base units

These units and their associated quantities are dimensionally independent.

metre
Unit symbol: **m**

kilogram
Unit symbol: **kg**

second
Unit symbol: **s**

ampere
Unit symbol: **A**

kelvin
Unit symbol: **K**

mole
Unit symbol: **mol**

candela
Unit symbol: **cd**

Supplementary units

radian
Unit symbol: **rad**

steradian
Unit symbol: **sr**

Some derived units with special names

Frequency hertz Hz

Force newton N

Energy joule J

Power watt W

Pressure pascal Pa

Electric charge coulomb C

Electric potential difference volt V

Electric resistance ohm Ω

Activity (of a radioactive source; nuclear transformations per unit time) Becquerel Bq

Absorbed dose (of ionizing radiation) gray Gy

Dose equivalent (of ionizing radiation) sievert SV

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