UNIVERSITY OF CAMBRIDGE

# NATURAL SCIENCES ADMISSIONS ASSESSMENT

# CONTENT SPECIFICATION

2018

## Overview

The Natural Sciences Admissions Assessment consists of two sections:

**Section 1** consists of five parts, of which candidates should answer three. Each part contains 18 multiple-choice questions. The time allowed for Section 1 is 80 minutes. Calculators may NOT be used in Section 1.

**Section 2** consists of six questions of which candidates should answer any two. The time allowed for Section 2 is 40 minutes. Calculators may be used in Section 2.

The purpose of the Natural Sciences Admissions Assessment is to determine a candidate's potential to achieve in an academically demanding undergraduate degree course. Questions draw upon a candidate's ability to use and apply their scientific and mathematical knowledge. The assessment is designed to be challenging in order to differentiate effectively between able applicants, including those who may have achieved the highest possible grades in school examinations.

The regulations for the use of calculators in Appendix 3 apply to Section 2 of this assessment.

### Format

Section 1 consists of five parts. **Candidates will be required to answer Part A, and two further parts chosen from B, C, D, and E.** The five parts are as follows:

| | |
|---|---|
| Part A | Mathematics |
| Part B | Physics |
| Part C | Chemistry |
| Part D | Biology |
| Part E | Advanced Mathematics and Advanced Physics |

There are 18 multiple-choice questions in each part, and each candidate will therefore be required to answer a total of 54 questions. The time allowed to complete Section 1 is 80 minutes and candidates should be careful to manage their time accordingly. Results for each part will be reported separately. Calculators may NOT be used in Section 1.

Section 2 consists of six questions, two each on Biology, Chemistry and Physics. Candidates should answer **any two questions**. The time allowed to complete Section 2 is 40 minutes. The answers will be handwritten; candidates may also be expected to draw diagrams and analyse data (including drawing graphs). If one part of a question cannot be done, later parts might still be solvable. Calculators may be used for Section 2.

Example questions for Section 1 and Section 2 are given in Appendix 4.

## Content

**Section 1:** The questions in Section 1 will draw upon the topics listed in Appendix 1.

In Section 1, all parts will assume knowledge of the mathematical content of Part A (Mathematics). Part E (Advanced Mathematics and Advanced Physics) will also assume knowledge of the content of Part B (Physics). Appendix 1 lists the knowledge assumed for each part.

**Section 2:** The questions in Section 2 assume knowledge of the content listed in Appendix 2, but may require the application of the related scientific principles in an unfamiliar context.

In addition, each subject in Section 2 assumes the corresponding subject knowledge for Section 1. All subjects in Section 2 will also assume knowledge of the mathematical content for Section 1 Part A. Physics questions in Section 2 will assume ALL the knowledge for Section 1 Part B and Part E. In summary, for Section 2:

<table>
<tr><th></th><th colspan="3">Assumed knowledge for Section 2</th></tr>
<tr><td>Biology</td><td>Section 2 Biology</td><td>Section 1 Part D: Biology</td><td rowspan="3">Section 1 Part A: Mathematics</td></tr>
<tr><td>Chemistry</td><td>Section 2 Chemistry</td><td>Section 1 Part C: Chemistry</td></tr>
<tr><td>Physics</td><td>Section 2 Physics</td><td>Section 1 Part B: Physics<br>Section 1 Part E: Advanced Mathematics and Advanced Physics</td></tr>
</table>

## Scoring

In Section 1, each correct answer will score 1 mark. No marks are deducted for incorrect answers. Results for each part will be reported separately.

In Section 2, each question is marked out of 25, with the marks for each part of the question indicated on the paper. No marks are deducted for incorrect answers.

# Appendix 1: Knowledge assumed in Section 1

The following material outlines the scientific and mathematical knowledge that the Natural Sciences Admissions Assessment Section 1 questions can draw upon. Throughout this specification it should be assumed that, where mention is made of a particular quantity, knowledge of the SI unit of that quantity is also expected (including the relationship of the unit to other SI units through the equations linking their quantities). Candidates will be expected to be familiar with the SI prefixes (for the range $10^{-9}$ (nano) to $10^{9}$ (giga)) when used in connection with any SI unit.

## Part A Mathematics

### A1. Number

**A1.1** Order, add, subtract, multiply and divide whole numbers, integers, fractions, decimals and numbers in index form.

**A1.2** Use the concepts and vocabulary of factor, multiple, common factor, highest common factor (hcf), least common multiple (lcm), composite (i.e. not prime), prime number, and prime factor decomposition.

**A1.3** Use the terms ‘square’, ‘positive square root’ and ‘negative square root’, ‘cube’ and ‘cube root’.

**A1.4** Use index laws to simplify, multiply, and divide integer, fractional, and negative powers.

**A1.5** Interpret, order and calculate with numbers written in standard index form.

**A1.6** Understand equivalent fractions.

**A1.7** Convert between fractions, decimals and percentages.

**A1.8** Understand and use percentage, including repeated proportional change and calculating the original amount after a percentage change.

**A1.9** Understand and use direct and indirect proportion.

**A1.10** Use ratio notation including dividing a quantity in a given ratio, and solve related problems (using the unitary method).

**A1.11** Understand and use number operations, including inverse operations and the hierarchy of operations.

**A1.12** Use surds and $\pi$ in exact calculations, simplify expressions that contain surds, including rationalising the denominator.

**A1.13** Calculate upper and lower bounds in contextual problems.

**A1.14** Approximate to a specified and appropriate degree of accuracy, including rounding to a given number of decimal places or significant figures.

**A1.15** Know and use approximation methods to produce estimations of calculations.

## A2. Algebra

**A2.1** Distinguish between the different roles played by letter symbols.

**A2.2** Manipulate algebraic expressions by collecting like terms; by multiplying a single term over a bracket; by expanding the product of two linear expressions.

**A2.3** Use index laws in algebra for multiplication and division of integer, fractional, and negative powers.

**A2.4** Set up and solve linear equations, including simultaneous equations in two unknowns.

**A2.5** Factorise quadratics, including the difference of two squares. Simplify rational expressions by cancelling or factorising.

**A2.6** Set up quadratic equations and solve them by factorising.

**A2.7** Set up and use equations to solve problems involving direct and indirect proportion.

**A2.8** Derive a formula, substitute into a formula.

**A2.9** Change the subject of a formula.

**A2.10** Solve linear inequalities in one or two variables.

**A2.11** Generate terms of a sequence using 'term-to-term' and 'position-to-term' definitions.

**A2.12** Use linear expressions to describe the $n^{th}$ term of a sequence.

**A2.13** Use Cartesian coordinates in all 4 quadrants.

**A2.14** Recognise the equations of straight lines; understand $y = mx + c$ and the gradients of parallel lines.

**A2.15** Understand that the intersection of graphs can be interpreted as giving the solutions to simultaneous equations.

**A2.16** Solve simultaneous equations, where one is linear and one is quadratic.

**A2.17** Recognise and interpret graphs of quadratic functions, simple cubic functions, the reciprocal function, trigonometric functions, and the exponential function $y = k^x$ for simple positive values of $k$.

**A2.18** Construct linear functions from real-life problems; interpret graphs modelling real situations.

## A3. Geometry

**A3.1** Recall and use properties of angles at a point, on a straight line, perpendicular lines and opposite angles at a vertex.

**A3.2** Understand and use the angle properties of parallel lines, intersecting lines, triangles and quadrilaterals.

**A3.3** Calculate and use the sums of the interior and exterior angles of polygons.

**A3.4** Recall the properties and definitions of special types of quadrilateral.

**A3.5** Recognise and use reflectional and rotational symmetry of 2-dimensional shapes.

**A3.6** Understand congruence and similarity.

**A3.7** Use Pythagoras' theorem in 2-dimensions and 3-dimensions.

**A3.8** Understand and construct geometrical proofs, including using circle theorems:

- **a.** the perpendicular from the centre to a chord bisects the chord
- **b.** the tangent at any point on a circle is perpendicular to the radius at that point
- **c.** the angle subtended by an arc at the centre of a circle is twice the angle subtended at any point on the circumference
- **d.** the angle in a semicircle is a right angle
- **e.** angles in the same segment are equal
- **f.** the opposite angles in a cyclic quadrilateral add to 180°
- **g.** the angle between the tangent and chord at the point of contact is equal to the angle in the alternate segment.

**A3.9** Use 2-dimensional representations of 3-dimensional shapes.

**A3.10** Describe and transform 2-dimensional shapes using single or combined rotations, reflections, translations, or enlargements, including the use of vector notation.

**A4. Measures**

**A4.1** Calculate perimeters and areas of shapes made from triangles, rectangles and other shapes.

**A4.2** Find circumferences and areas of circles, including arcs, segments and sectors.

**A4.3** Calculate the volumes and surface areas of right prisms, pyramids, spheres, cylinders, cones, and solids made from cubes and cuboids (formulae will be given for the sphere and cone).

**A4.4** Use vectors, including the sum of two vectors, algebraically and graphically.

**A4.5** Use and interpret maps and scale drawings.

**A4.6** Understand and use the effect of enlargement for perimeter, area, and volume of shapes and solids.

**A4.7** Convert measurements from one unit to another, including between imperial and metric (conversion factors will be given for imperial/metric conversions).

**A4.8** Know the SI prefixes for the range $10^{-9}$ (nano) to $10^{9}$ (giga) when used in connection with any SI unit.

**A4.9** Recognise the inaccuracy of measurement.

**A4.10** Understand and use three-figure bearings.

**A4.11** Understand and use compound measures.

## A5. Statistics

**A5.1** Identify possible sources of bias.

**A5.2** Identify flaws in data collection sheets and questionnaires in a survey or experiment.

**A5.3** Group, and understand, discrete and continuous data.

**A5.4** Extract data from lists and tables.

**A5.5** Design and use two-way tables.

**A5.6** Interpret bar charts, pie charts, grouped frequency diagrams, line graphs, and frequency polygons.

**A5.7** Interpret cumulative frequency tables, graphs, and histograms (including unequal class width).

**A5.8** Calculate and interpret mean, median, mode, modal class, range, and inter-quartile range, including the estimated mean of grouped data.

**A5.9** Calculate average rates when combining samples or events, including solving problems involving average rate calculations (e.g. average survival rates in different wards of different sizes; average speed of a car over a journey where it has travelled at different speeds).

**A5.10** Interpret scatter diagrams and recognise correlation; using lines of best fit.

**A5.11** Compare sets of data by using statistical measures or by interpreting graphical representations of their distributions.

## A6. Probability

**A6.1** Understand and use the vocabulary of probability and the probability scale.

**A6.2** Understand and use estimates or measures of probability, including relative frequency and theoretical models.

**A6.3** List all the outcomes for single and combined events.

**A6.4** Identify different mutually exclusive outcomes and know that the sum of the probabilities of all these outcomes is 1.

**A6.5** Construct and use Venn diagrams to solve union and intersection categorisation problems and determine probabilities when required. Familiarity with the meaning and use of the terms ‘union’, ‘intersection’, and ‘complement’ is required.

**A6.6** Know when to add or multiply two probabilities.

**A6.7** Understand the use of tree diagrams to represent outcomes of combined events:

- **a.** when the probabilities are independent of the previous outcome
- **b.** when the probabilities are dependent on the previous outcome.

**A6.8** Compare experimental and theoretical probabilities.

**A6.9** Understand that if an experiment is repeated, the outcome may be different.

# Part B Physics

## B1. Electricity

**B1.1** Electric current:

- **a.** conductors and insulators
- **b.** current = charge / time
- **c.** use of voltmeter and ammeter
- **d.** resistance = voltage / current
- **e.** V-I graphs for a fixed resistor and a filament lamp
- **f.** series and parallel circuits – current and voltage rules
- **g.** resistor combinations in series (but not parallel)
- **h.** voltage = energy / charge.

**B1.2** Basic circuit symbols and diagrams.

**B1.3** Power and energy:

- **a.** power = current × voltage
- **b.** energy transfer = power × time = $VIt$.

## B2. Motion and energy

**B2.1** Kinematics:

- **a.** speed = distance / time
- **b.** difference between speed and velocity
- **c.** acceleration = change in velocity / time
- **d.** distance-time and velocity-time graphs
- **e.** calculations using gradients and areas under graphs
- **f.** average speed.

**B2.2** Forces and motion:

- **a.** inertia and Newton's first law
- **b.** momentum = mass × velocity
- **c.** conservation of momentum
- **d.** Newton's second law: force = mass × acceleration
- **e.** force = rate of change of momentum
- **f.** resultant force
- **g.** difference between mass and weight, and the relationship between them ($W = mg$)
- **h.** gravitational field strength (approximated as 10 N / kg on Earth)
- **i.** free-fall acceleration
- **j.** terminal velocity and forces involved

**k.** Newton's third law.

**B2.3** Energy:

**a.** work = force × distance moved in direction of force

**b.** appreciation of work done as a transfer of energy

**c.** potential energy = $mgh$

**d.** kinetic energy = $\frac{1}{2}mv^2$

**e.** applications to crumple zones and road safety – stopping distances

**f.** power = energy transfer / time.

**B2.4** Energy conversion:

**a.** law of conservation of energy

**b.** forms of energy

**c.** ideas of useful energy and wasted energy

**d.** percentage efficiency = (useful output / total input) × 100.

**B3. Thermal physics**

**B3.1** Conduction:

**a.** thermal conductors and insulators

**b.** factors affecting rate of conduction.

**B3.2** Convection:

**a.** fluid flow caused by differences in density

**b.** factors affecting rate of convection.

**B3.3** Radiation:

**a.** infrared radiation (see **B4.** Waves)

**b.** absorption and emission of radiation

**c.** factors affecting rate of absorption or emission.

**B3.4** Matter:

**a.** density = mass / volume

**b.** experimental determination of densities

**c.** comparison of densities of the three states.

**B4. Waves**

**B4.1** Wave nature:

**a.** transfer of energy without net movement of matter

**b.** examples (including electromagnetic waves, sound, seismic)

**c.** amplitude, wavelength, frequency and period

**d.** frequency = 1 / period, and the SI unit of frequency is hertz (Hz), 1 Hz means 1 wave per second

**e.** speed = distance / time

**f.** wave speed = frequency × wavelength.

**B4.2** Sound waves:

**a.** ultrasound and uses (sonar, scanning, animals).

**B5. Electromagnetic spectrum**

**B5.1** EM waves:

**a.** nature and properties of electromagnetic waves (transverse, travel at speed of light in vacuum).

**B5.2** The spectrum:

**a.** parts of the spectrum (radio waves, microwaves, IR, visible light, UV, X-rays, gamma)

**b.** distinction by different wavelengths, frequencies

**c.** order of component parts by wavelength, frequency

**d.** applications

**e.** dangers.

**B6. Radioactivity**

**B6.1** Atomic structure:

**a.** protons, neutrons and electrons

**b.** popular models of atomic structure

**c.** relative charges and masses of sub-atomic particles

**d.** atomic number, atomic mass

**e.** isotopes

**f.** ionisation caused by gain or loss of electrons.

**B6.2** Radioactive decay:

**a.** emissions from the nucleus

**b.** random and spontaneous nature

**c.** alpha, beta and gamma emission

**d.** nature of alpha and beta particles, gamma radiation

**e.** radioactive decay equations

**f.** effect of decay on atomic number and mass

**g.** activity of a radioactive sample.

**B6.3** Ionising radiation:

**a.** penetrating abilities of alpha, beta and gamma

**b.** ionising abilities of alpha, beta and gamma

**c.** background radiation – existence and origins

**d.** applications, dangers and hazards of ionising radiation.

**B6.4** Half-life:

**a.** decrease in activity over time

**b.** graphical representation of decay (including of decay products)

**c.** meaning of half-life.

**B6.5** Nuclear fission:

**a.** caused by absorption of neutrons

**b.** fission of uranium-235, including equation

**c.** chain reaction.

**B6.6** Nuclear fusion:

**a.** fusion of hydrogen to form helium

**b.** need for high temperatures

**c.** significance as an energy source.

# Part C Chemistry

## C1. Atomic structure

**C1.1** Describe the structure of the atom as a central nucleus (containing protons and neutrons) surrounded by electrons moving in shells/energy levels/orbits.

**C1.2** Know the relative masses and charges of protons, neutrons and electrons and recognise most of the mass of an atom is in the nucleus.

**C1.3** Know that atomic number = number of protons.

**C1.4** Know that mass number = number of protons + number of neutrons.

**C1.5** Understand that in an atom the number of protons = the number of electrons so that atoms have no overall charge.

**C1.6** Use the standard notation (e.g. ${}^{12}_{6}\mathrm{C}$) for any atom to calculate the number of protons, neutrons and electrons in an atom (and so any ion of the atom).

**C1.7** Use the atomic number to write the electronic configurations of the first 20 elements in the periodic table (H to Ca) in the comma separated format (e.g. 2,8,8,1 for a potassium atom).

**C1.8** Define isotopes as atoms of an element with the same number of protons but different numbers of neutrons (so having different mass numbers). Use data to identify the relative abundances of isotopes.

**C1.9** Know and use the concept of relative atomic mass, $A_r$.

**C1.10** Use $A_r$ values to calculate the relative molecular (formula) mass, $M_r$, of a compound.

**C1.11** Understand that chemical composition can be identified from spectra.

## C2. The periodic table (IUPAC)

**C2.1** Know that Periods are horizontal rows and Groups are vertical columns.

**C2.2** Recall the position of metals and non-metals in the table.

**C2.3** Understand the use of displacement reactions in establishing the order of reactivity of metals.

**C2.4** Explain how the uses of metals are related to their physical and chemical properties, e.g. Al, Fe, Cu, Ag, Au, Ti.

**C2.5** Know that most metal ores are the oxides of the metal, and that the extraction of metals always involves reduction processes.

**C2.6** Know the position of the alkali metals (Group 1), alkaline earth metals (Group 2), the halogens (Group 17), the noble gases (Group 18).

**C2.7** Know and use the relationship between the position of an atom in the periodic table (Group and Period) and the electronic configuration of the atom.

**C2.8** Know that the elements are arranged in the order of increasing atomic number.

**C2.9** Know the physical and chemical properties of the alkali metals (Group 1), the halogens (Group 17), the noble gases (Group 18).

**C2.10** Know the position in the periodic table of the transition metals (*d*-block elements) and their common properties (coloured ions, multiple stable ions, use as catalysts).

**C2.11** Demonstrate an understanding that elements with relative atomic masses that are not whole numbers (e.g. Cl) have isotopes that are responsible for this fact.

**C2.12** Calculate the relative atomic mass of an element from its isotopes given their relative isotopic masses and their relative abundances.

**C3. Chemical reactions and equations**

**C3.1** Know and understand each of the following:

- **a.** in a chemical reaction, new substances are formed by the rearrangement of atoms but none are destroyed or created. Energy may be absorbed or released by the reaction
- **b.** a chemical reaction can be described using a word equation
- **c.** the → symbol is used to show a reaction where all the reactant can be converted into products (when the correct reacting amounts are used)
- **d.** formulae for a compound can be written from:
  - **i.** the names of many covalent compounds, e.g. $SO_3$ as sulfur trioxide
  - **ii.** recall of the names of some common compounds, e.g. $H_2SO_4$ as sulfuric acid
  - **iii.** the ionic charges for ionically bonded compounds. Cations (positive ions) for metal elements can be found from their Group number in the periodic table, as can the anions (negative ions) of non-metal ions. The charges of polyatomic anions need to be learnt, e.g. $CO_3^{2-}$ and $OH^-$. Where a cation can have more than one charge, e.g. Cu, Fe, then Roman numerals are used, e.g. iron(III) chloride as $FeCl_3$
- **e.** word equations can be turned into balanced chemical equations using the formulae of compounds and the symbols of elements. State symbols for each species in a chemical reaction can be added to a fully balanced chemical equation (s, l, g, aq)
- **f.** how to write balanced ionic equations either from a balanced chemical equation or to represent the processes, for example in electrolysis and redox
- **g.** in some chemical reactions, all the reactants never turn into all the products. These equations use the symbol ⇌ and are called reversible

**h.** factors that can affect the position of the equilibrium and the rate at which the equilibrium is achieved (reactants, products, catalysts, temperature, pressure).

**C4. Quantitative Chemistry**

**C4.1** Know that 1 mole of a substance is the $A_r$ or $M_r$ in grams and perform conversions of grams to moles and vice versa (including working in tonnes and kilograms).

**C4.2** When given the molar volume of a gas (1 mole of any gas occupies 24 $dm^3$ at rtp and 22.4 $dm^3$ at stp), calculate mass or moles to volume and vice versa.

**C4.3** Calculate the percentage composition by mass of a compound given the $A_r$ values.

**C4.4** Find the empirical formula of a compound given the percentage composition by mass of the elements present and the $A_r$ values. Find the molecular formula from the empirical formula if given the $M_r$ value.

**C4.5** Use balanced chemical equations to calculate the masses of reactants and products. Then perform scaling from the reacting ratio in the equation to find any reactant that may be in excess or amounts of reactants that completely react with each other (limiting reactants).

**C4.6** For balanced chemical equations involving only gases, be able to arrive at the mole ratio of reacting volumes of gases (or vice versa) or the ratio for the balanced equation as a whole.

**C4.7** For solutions:

**a.** understand that concentration is in mol $dm^{-3}$ and be able to calculate the concentration given the moles (or grams) and the volume of water by using the equation:

$$\text{number of moles} = \frac{\text{volume cm}^3}{1000} \times \text{concentration mol dm}^{-3}$$

(or any of the other variations of this equation). Find any of the three quantities in the equation if given two of the others

**b.** use the concentrations of solutions (or find the concentrations from given data) and the reacting ratio of reactants from the balanced equation to perform titration calculations.

**C4.8** Calculate the percentage yield of a reaction using the balanced chemical equation and the equation:

$$\text{percentage yield} = \frac{\text{actual yield (g)}}{\text{predicted yield (g)}} \times 100$$

**C4.9** Be able to give logical reasons why, in practical situations, the percentage yield is rarely 100%.

**C5. Oxidation, reduction and redox**

**C5.1** Know that on a basic level, oxidation is the gain of oxygen or the removal of hydrogen and that reduction is the removal of oxygen or the addition of hydrogen.

**C5.2** Identify any reaction as being oxidation only, reduction only, redox (both oxidation and reduction taking place) or no change in oxidation/reduction.

**C5.3** Link oxidation and reduction to the transfer of electrons, i.e. reduction as a gain of electrons and oxidation as a loss of electrons.

**C6. Chemical bonding, structure and properties**

**C6.1** Know definitions of elements and of compounds, and the distinction between them.

**C6.2** Understand that the reason atoms react to form compounds is to attain the electronic configuration of a noble gas (the most stable configuration in the periodic table). Understand that the type of bonding taking place depends on the atoms involved in the reaction:

- **a.** understand the characteristics of ionic, covalent (simple and giant) and metallic bonding, and recognise examples of each
- **b.** understand the structure and properties of ionically, covalently (simple and giant) and metallically bonded structures.

**C7. Group Chemistry**

**C7.1** Group 1 (alkali metals):

- **a.** recognise that Group 1 metals are highly reactive, and then define metals as electron donors producing cations
- **b.** describe the physical properties as being soft and having, for metals, relatively low melting and boiling points. Explain the need for storing the metals under oil (reaction with moist air)
- **c.** know that reactivity increases down Group 1
- **d.** describe what is observed when the metals react with:
  - **i.** water
  - **ii.** oxygen
  - **iii.** Group 17 (halogens).

  For the above reactions, write balanced chemical equations (including state symbols).

**C7.2** Group 17 (halogens):

- **a.** recognise that the halogens are the most reactive non-metals (defining non-metals as acceptors of electrons so forming anions)

**b.** know that reactivity decreases down the group

**c.** explain what is meant by a displacement reaction (in terms of reactivity competition) and how the reactions between halogens and other halide ions can be used to establish the order of reactivity. Be able to write ionic equations for these reactions (including state symbols)

**d.** describe the tests for chloride, bromide and iodide ions using silver nitrate solution.

**C7.3** Group 18 (noble gases):

**a.** describe noble gases as the least reactive of the elements in the periodic table, and relate this to their electronic configurations.

**C7.4** Transition metals (*d*-block elements):

**a.** identify the position of the *d*-block elements in the periodic table

**b.** describe transition metals as having the following properties:

**i.** forming different stable ions in different conditions

**ii.** forming coloured compounds

**iii.** used as catalysts (as ions or atoms).

**C8. Separation techniques**

**C8.1** Know that chemical procedures are capable of separating:

**a.** compounds (by chemical reactions, e.g. displacement or electrolysis)

**b.** mixtures (defined as substances that may be mixed together but not chemically joined).

**C8.2** Know that mixtures include:

**a.** liquids as **miscible** (can be separated by using fractional distillation because of the differences in boiling points, or paper chromatography (including use of $R_f$ values)) or **immiscible** (the layers can be removed one at a time using a separating funnel)

**b.** soluble solids mixed with insoluble solids (using dissolving, filtering, evaporation or distillation and crystallisation).

**C9. Acids, bases and salts**

**C9.1** Know the definitions, properties and reactions of strong and weak acids and bases. To include acid categorisations such as: strong, weak, and mono-, di-, tri-, poly-protic/basic.

**C10. Rates of reaction**

**C10.1** Describe the qualitative effects on a rate of reaction of concentration, temperature, particle size, catalyst and, for gases, pressure.

**C10.2** Know that the rate of reaction can be found by measuring the loss of a reactant or gain of a product measured over time.

**C10.3** Given the balanced chemical equation (including state symbols), be able to identify which reactant decrease or product increase can be measured, e.g. loss in mass, production of a gas, electrical conductivity or thermal conductivity. Describe practical procedures to measure such changes.

**C10.4** Interpret data in graphical form about the rate of a reaction.

**C10.5** Use collision theory to explain that for a reaction to occur, particles must come into contact and not every collision causes a reaction. Explain that particles must have sufficient energy when they collide to produce change, and that this energy is called the activation energy ($E_a$).

**C10.6** Explain, using collision theory, the effect on reaction rate of changing the temperature, changing surface area, changing concentration, adding a catalyst and, for gases, changing pressure.

**C10.7** Recognise that catalysts are unchanged at the end of a reaction and are not used up in the reaction (although there may be some physical changes, e.g. lumps to powder).

**C11. Energetics**

**C11.1** Understand the concepts of exothermic ($\Delta H$ –ve values) and endothermic reactions ($\Delta H$ +ve values), their energy level profiles and the effect of catalysts on them.

**C12. Electrolysis**

**C12.1** Be able to explain the terms ‘electrode’, ‘cathode’, ‘anode’ and ‘electrolyte’.

**C12.2** Recognise that in electrolysis at the cathode, the cations receive electrons (reduction) to change into atoms or molecules and at the anode, the anions lose electrons to form atoms or molecules (oxidation).

**C12.3** Be able to outline the electrolysis of the following:

- **a.** brine (sodium chloride solution) including the concept of preferential discharge of ions
- **b.** electroplating using copper (copper sulfate).

For each of the above processes, write half-equations for the processes taking place at each electrode.

# Part D Biology

## D1. Cells

**D1.1** Describe the structure and function of animal cells to include:

- **a.** cell membrane
- **b.** cytoplasm
- **c.** nucleus
- **d.** mitochondrion.

**D1.2** Describe the structure and function of plant cells to include:

- **a.** cell membrane
- **b.** cytoplasm
- **c.** nucleus
- **d.** cell wall
- **e.** chloroplast
- **f.** mitochondrion
- **g.** vacuole.

**D1.3** Describe the structure and function of a bacterial cell to include:

- **a.** cell membrane
- **b.** cytoplasm
- **c.** cell wall
- **d.** chromosomal DNA/no ‘true’ nucleus.

**D1.4** Know the levels of organisation as: cells to tissues to organs.

## D2. Movement across membranes

**D2.1** Know the definition of and examples of diffusion, osmosis and active transport.

## D3. Cell division and sex determination

**D3.1** Mitosis:

- **a.** define as cell division that produces two daughter cells that have the same number of chromosomes as the mother cell, so are genetically identical
- **b.** describe the role of mitosis in growth and repair of tissues, plus replacement of cells.

**D3.2** Meiosis:

- **a.** define as cell division that produces four daughter cells, known as gametes, which have a single set of chromosomes (are haploid), each with different combinations of parent cells’ DNA

**b.** describe the role of meiosis in reducing the chromosome number so that full chromosome complement, two sets of chromosomes (diploid), is restored at fertilisation.

**D3.3** Asexual and sexual reproduction:

**a.** understand that asexual reproduction involves one parent and offspring are genetically identical

**b.** understand that asexual reproduction produces clones

**c.** understand that sexual reproduction involves two parents and offspring are genetically different, leading to (increased) variation

**d.** understand that bacteria reproduce asexually by dividing into two by binary fission.

**D3.4** Sex determination:

**a.** recall that, in most mammals, females are XX and males are XY

**b.** know that one of the pairs of chromosomes, XX or XY, carries the genes which determine sex.

**D4. Inheritance**

**D4.1** Know the nucleus as a site of genetic material/chromosomes/genes in plant and animal cells.

**D4.2** Describe and understand the following genetic terms:

**a.** genes

**b.** alleles

**c.** dominant

**d.** recessive

**e.** heterozygous

**f.** homozygous

**g.** phenotype

**h.** genotype.

**D4.3** Monohybrid crosses:

**a.** use and interpret genetic diagrams to depict monohybrid crosses

**b.** use family pedigrees/family trees

**c.** express outcome as ratio, numbers or percentage

**d.** understand the concept of inherited disease and the use of screening to identify it, e.g. cystic fibrosis.

**D5. DNA**

**D5.1** Understand that chromosomes contain DNA.

**D5.2** Describe the structure of DNA:

- **a.** know that one molecule of DNA is made up of two long chains (strands) of alternating sugar and phosphate molecules connected by bases and that this structure is twisted to form a double helix
- **b.** know that each of the two DNA strands is made up of many small groups of nucleotides containing four bases: adenine (A), thymine (T), cytosine (C) and guanine (G)
- **c.** know that A pairs with T, and C pairs with G, and that it is the order of these bases which forms a code.

**D5.3** Protein synthesis:

- **a.** understand that genes carry the code for proteins
- **b.** understand that the genetic code is 'read' as triplets and each triplet codes for an amino acid
- **c.** understand that protein synthesis involves the production of proteins from amino acids.

**D5.4** Gene mutations:

- **a.** appreciate that a change in the gene/DNA is a gene mutation and that mutations occur at random
- **b.** understand that most mutations have no effect but some may be beneficial or harmful.

**D6. Gene technologies**

**D6.1** Genetic modification/genetic engineering:

- **a.** know that genes from the chromosomes of humans and other organisms can be 'cut out' using enzymes and transferred to cells of other organisms
- **b.** recall examples of genetic modification in different cell types.

**D6.2** Stem cells:

- **a.** understand that embryonic stem cells can give rise to any cell type
- **b.** understand cells lose this ability as an animal matures
- **c.** recall that there are embryonic and adult stem cells.

**D7. Variation**

**D7.1** Natural selection and evolution:

- **a.** understand the sequence as (1) variation (2) leads to differential survival (3) as those best adapted survive; (4) these can reproduce (5) and pass on

genes/alleles/characteristics to the next generation

**b.** recall antibiotic-resistance/MRSA as an example of evolution through natural selection.

**D7.2** Sources of variation:

**a.** understand that variation can be genetic/inherited

**b.** understand that variation can be environmental.

**D7.3** Extinction:

**a.** understand that extinction can occur if organisms cannot adapt quickly enough.

**D8. Enzymes**

**D8.1** Enzyme function:

**a.** know that chemical reactions in cells are controlled by enzymes and that enzymes are proteins made by living things

**b.** know that enzymes speed up/catalyse the rate of chemical reactions.

**D8.2** Understand the mechanism of enzyme action in terms of the ‘lock and key’ hypothesis:

**a.** understand that the specific shape of an enzyme enables it to function.

**D8.3** Understand how the following factors affect the rate of enzyme action:

**a.** temperature

**b.** pH

**c.** substrate concentration.

**D8.4** Digestive enzymes:

**a.** know the role of amylase (breaks down starch into maltose), protease (breaks down proteins into amino acids) and lipase (breaks down lipids into fatty acids and glycerol) in digestion.

**D9. Animal physiology**

**D9.1** Respiration:

**a.** define respiration

**b.** describe aerobic respiration

**c.** recall the word equation for aerobic respiration

**d.** describe anaerobic respiration in animals

**e.** recall the word equation for anaerobic respiration in animals

**f.** compare aerobic respiration with anaerobic respiration in animals

**g.** describe the effect on the cells of changing energy requirements, including changes to exchange of oxygen and carbon dioxide.

**D9.2** Central Nervous System (CNS):

- **a.** know that sense organs are groups of receptor cells which respond to stimuli (light, sound, touch, temperature, chemicals) and then relay this information as electrical impulses along neurons to the CNS
- **b.** understand the specific effects of alcohol and drugs on the nervous system (including reaction times).

**D10. Plant physiology**

**D10.1** Photosynthesis:

- **a.** recall how and why factors affect the rate of photosynthesis, including temperature, carbon dioxide and light intensity and understand these as being limiting factors
- **b.** understand the importance of photosynthesis in plants and the role of chlorophyll
- **c.** recall the chemical reactions of photosynthesis in a cell are controlled by enzymes
- **d.** recall the word equation for photosynthesis
- **e.** understand that relative rates of respiration and photosynthesis affect the exchange of carbon dioxide and oxygen in plants.

**D10.2** Response:

- **a.** interpret data on the positive response of plant shoots to light (phototropism)
- **b.** explain how phototropism is due to a plant hormone.

**D11. Environment**

**D11.1** Food chains:

- **a.** understand the flow of energy in a food chain including:
  - **i.** light energy from the sun
  - **ii.** chemical energy in organisms used in repair and maintenance and growth of cells
  - **iii.** transfer (loss) of the chemical energy to the environment in waste materials and as heat from respiration.

**D11.2** Population size:

- **a.** appreciate that a population can change in size
  - **i.** increasing when resources (including food, light, minerals, water) are available and not limited

ii. decreasing if resources are in short supply or become limiting as a result of competition between species (interspecific) or within a population (intraspecific).

**D11.3** Cycles:

a. understand that nutrients are released in decay and that nutrients are then taken up by other organisms resulting in nutrient cycles

b. recall the carbon cycle to include the following processes:

i. photosynthesis

ii. respiration

iii. combustion

iv. decomposition.

**D11.4** Pollution:

a. understand that living organisms can be used as indicator species for levels of pollution in:

i. air (sulfur dioxide concentration) – lichens

ii. polluted water (low oxygen concentration) – invertebrates e.g. bloodworm

iii. clean water (high oxygen concentration) – invertebrates e.g. stonefly.

**D11.5** Variety of life:

a. understand that living organisms show a range of sizes, features and complexity and explain that the similarities are used to group organisms

b. list the main features used to group organisms:

i. plants into non-flowering (e.g. ferns) and flowering plants

ii. animals into invertebrates and vertebrates

iii. microorganisms into fungi, bacteria and algae.

c. explain that classification is based on morphology, anatomy and DNA.

**D11.6** Biodiversity:

a. understand how quadrats are used to investigate the distribution of species

b. calculate the density of a species by counting the number of individual plants of a particular species in each quadrat, and calculating the mean number of individuals per unit area

c. calculate the frequency of occurrence using the equation:

$$\text{frequency of occurrence} = \frac{\text{number of quadrats the species occurs in}}{\text{total number of quadrats}}$$

# Part E Advanced Mathematics and Advanced Physics

## E1. Algebra and functions

**E1.1** Laws of indices for all rational exponents.

**E1.2** Use and manipulation of surds; simplifying expressions that contain surds, including rationalising the denominator; for example, simplifying $\frac{\sqrt{5}}{3+2\sqrt{5}}$, and $\frac{3}{\sqrt{7}-2\sqrt{3}}$.

**E1.3** Quadratic functions and their graphs; the discriminant of a quadratic function; completing the square; solution of quadratic equations.

**E1.4** Simultaneous equations: analytical solution by substitution, e.g. of one linear and one quadratic equation.

**E1.5** Solution of linear and quadratic inequalities.

**E1.6** Algebraic manipulation of polynomials, including:

- **a.** expanding brackets and collecting like terms
- **b.** factorisation and simple algebraic division (by a linear polynomial, including those of the form $ax + b$)
- **c.** use of the Factor Theorem and the Remainder Theorem.

## E2. Sequences and series

**E2.1** Sequences, including those given by a formula for the n$^{th}$ term and those generated by a simple recurrence relation of the form $x_{n+1} = f(x_n)$.

**E2.2** Arithmetic series, including the formula for the sum of the first $n$ natural numbers.

**E2.3** The sum of a finite geometric series; the sum to infinity of a convergent geometric series, including the use of $|r| < 1$.

**E2.4** Binomial expansion of $(1 + x)^n$ for positive integer $n$; the notations $n!$ and $\binom{n}{r}$.

## E3. Coordinate geometry in the (x,y) plane

**E3.1** Equation of a straight line, including $y - y_1 = m(x - x_1)$ and $ax + by + c = 0$; conditions for two straight lines to be parallel or perpendicular to each other; finding equations of straight lines given information in various forms.

**E3.2** Coordinate geometry of the circle: using the equation of a circle in the forms $(x - a)^2 + (y - b)^2 = r^2$, and $x^2 + y^2 + cx + dy + e = 0$.

**E3.3** Use of the following circle properties:

- **a.** the perpendicular from the centre to a chord bisects the chord
- **b.** the tangent at any point on a circle is perpendicular to the radius at that point
- **c.** the angle subtended by an arc at the centre of a circle is twice the angle subtended by the arc at any point on the circumference
- **d.** the angle in a semicircle is a right angle

**e.** angles in the same segment are equal

**f.** the opposite angles in a cyclic quadrilateral add to 180°

**g.** the angle between the tangent and chord at the point of contact is equal to the angle in the alternate segment.

**E4. Trigonometry**

**E4.1** The sine and cosine rules, and the area of a triangle in the form $\frac{1}{2}ab\sin C$. The sine rule includes an understanding of the 'ambiguous' case (angle-side-side). Problems might be set in 2- or 3-dimensions.

**E4.2** Radian measure, including use for arc length and area of sector and segment.

**E4.3** The values of sine, cosine and tangent for the angles $0°,\ 30°,\ 45°,\ 60°,\ 90°$.

**E4.4** The sine, cosine, and tangent functions; their graphs, symmetries, and periodicity.

**E4.5** Know and use $\tan\theta = \frac{\sin\theta}{\cos\theta}$ and $\sin^2\theta + \cos^2\theta = 1$.

**E4.6** Solution of simple trigonometric equations in a given interval (this may involve the use of the identities in **E4.5**); for example: $\sin x = -\frac{1}{\sqrt{3}}$ for $-\pi < x < \pi$; $\sin^2\left(x + \frac{\pi}{3}\right) = \frac{1}{2}$ for $-2\pi < x < 2\pi$; $12\cos^2 x + 6\sin x - 10 = 2$ for $0° < x < 360°$.

**E5. Exponentials and logarithms**

**E5.1** $y = a^x$ and its graph, for simple positive values of $a$.

**E5.2** Laws of logarithms:

**a.** $a^b = c \Leftrightarrow b = \log_a c$

**b.** $\log_a x + \log_a y = \log_a(xy)$

**c.** $\log_a x - \log_a y = \log_a\left(\frac{x}{y}\right)$

**d.** $k\log_a x = \log_a(x^k)$

including the special cases:

**e.** $\log_a \frac{1}{x} = -\log_a x$

**f.** $\log_a a = 1$

Questions requiring knowledge of the change of base formula will not be set.

**E5.3** The solution of equations of the form $a^x = b$, and equations which can be reduced to this form, including those that need prior algebraic manipulation; for example, $3^{2x} = 4$, and $25^x - 3 \times 5^x + 2 = 0$.

**E6. Differentiation**

**E6.1** The derivative of $f(x)$ as the gradient of the tangent to the graph $y = f(x)$ at a point:

**a.** interpretation of a derivative as a rate of change

**b.** second order derivatives

**c.** knowledge of notation: $\frac{dy}{dx}$, $\frac{d^2y}{dx^2}$ , $f'(x)$, and $f''(x)$.

Differentiation from first principles is excluded.

**E6.2** Differentiation of $x^n$ for rational $n$, and related sums and differences. This might include some simplification before differentiating; for example, the ability to differentiate an expression such as $\frac{(3x+2)^2}{x^{\frac{1}{2}}}$ could be required.

**E6.3** Applications of differentiation to gradients, tangents, normals, stationary points (maxima and minima only), increasing and decreasing functions. Points of inflexion will not be examined.

**E7. Integration**

**E7.1** Definite integration as finding the 'area under a curve.'

**E7.2** Finding definite and indefinite integrals of $x^n$ for $n$ rational, $n \neq -1$, and related sums and differences, including expressions which require simplification prior to integrating; for example, $\int (x+2)^2 dx$, and $\int \frac{(3x-5)^2}{x^{\frac{1}{2}}} dx$.

**E7.3** An understanding of the Fundamental Theorem of Calculus and its significance to integration. Simple examples of its use may be required in the two forms:

$\int_a^b f(x)dx = F(b) - F(a)$, where $F'(x) = f(x)$, and $\frac{d}{dx}\int_a^x f(t)dt = f(x)$.

**E7.4** Combining integrals with either equal or contiguous ranges;

for example, $\int_2^5 f(x)dx + \int_2^5 g(x)dx = \int_2^5 [f(x) + g(x)]\, dx$,

and $\int_2^4 f(x)dx + \int_4^3 f(x)dx = \int_2^3 f(x)dx$.

**E7.5** Approximation of area under a curve using the trapezium rule; determination of whether this constitutes an overestimation or an underestimation.

**E7.6** Solving differential equations of the form $\frac{dy}{dx} = f(x)$.

**E8. Graphs of functions**

**E8.1** Recognise and be able to sketch the graphs of common functions that appear in this specification: these include lines, quadratics, cubics, trigonometric functions, logarithmic functions, and exponential functions.

**E8.2** Know the effect of simple transformations on the graph of $y = f(x)$ as represented by $y = af(x)$, $y = f(x) + a$, $y = f(x+a)$, $y = f(ax)$, with the value of $a$ positive or negative. Compositions of these transformations.

**E8.3** Understand how altering the values of $m$ and $c$ affects the graph of $y = mx + c$.

**E8.4** Understand how altering the values of $a$, $b$ and $c$ in $y = a(x+b)^2 + c$ affects the corresponding graph.

**E8.5** Use differentiation to help determine the shape of the graph of a given function; this might include finding stationary points (excluding inflexions) as well as finding when graphs are increasing or decreasing.

**E8.6** Use algebraic techniques to determine where the graph of a function intersects the coordinate axes; appreciate the possible number of real roots a general polynomial can possess.

**E8.7** Geometrical interpretation of algebraic solutions of equations; relationship between the intersections of two graphs and the solutions of the corresponding simultaneous equations.

**E9. Forces and equilibrium**

**E9.1** Understand the vector nature of force.

**E9.2** Find and use components and resultants.

**E9.3** Calculate the moment of a force about some point (2-dimensional situation only).

**E9.4** Understand the use of normal and frictional components of contact forces between two surfaces.

**E9.5** Understand and use the condition for a particle to be in equilibrium in simple situations – these might include a block resting on an inclined plane. Equilibrium here will be treated as objects being stationary.

**E9.6** Understand the terms ‘smooth’ and ‘rough’ and use the notion of limiting equilibrium.

**E9.7** Use the coefficient of friction in questions, including the relationships $F = \mu R$ and $F \leq \mu R$.

**E9.8** Understand the weight of a body acts through its centre of gravity; identify the position of the centre of gravity of simple planar bodies using symmetry.

**E9.9** Solve problems involving equilibrium of rigid bodies under coplanar forces.

**E10. Kinematics**

**E10.1** Understand graphical methods involving distance, displacement, speed, velocity, and acceleration.

**E10.2** Use graphical representation of 1-dimensional motion to make various deductions (for example, find the displacement from a velocity-time graph).

**E10.3** Solve questions involving the equations of motion:

**a.** $v = u + at$

**b.** $s = ut + \frac{1}{2}at^2$

**c.** $s = \frac{(u+v)t}{2}$

**d.** $v^2 = u^2 + 2as$

**E11. Newton's laws**

**E11.1** Apply Newton's laws to linear motion of point masses moving under the action of constant forces, including friction.

**E11.2** Model a body moving vertically, or on an inclined plane moving with constant acceleration (questions involving two perpendicular motions, e.g. parabolic flight, will not be examined).

**E11.3** Solve simple problems involving two bodies connected by a light inextensible string or rod (e.g. two bodies connected by a string over a light smooth pulley, or a car towing a caravan).

**E12. Momentum**

**E12.1** Understand and use the definition of linear momentum.

**E12.2** Understand and use the principle of conservation of momentum in 1-dimensional situations, including coalescence.

**E13. Energy**

**E13.1** Understand and use the concepts of gravitational potential energy and kinetic energy.

**E13.2** Understand and apply the principle of conservation of energy to simple situations.

# Appendix 2:

# Additional knowledge assumed in Section 2

Section 2 consists of six questions: two on Biology, two on Chemistry, and two on Physics. Candidates should answer **any two questions**.

Each question in Section 2 assumes knowledge of the relevant subject-specific content set out below. In addition, each subject in Section 2 assumes the corresponding subject knowledge for Section 1. All subjects in Section 2 will also assume knowledge of the mathematical content for Section 1 Part A. Physics questions in Section 2 will assume ALL the knowledge for Section 1 Part B and Part E. In summary:

<table>
<tr><th></th><th colspan="3">Assumed knowledge for Section 2</th></tr>
<tr><td>Biology questions</td><td>Section 2 Biology</td><td>Section 1 Part D: Biology</td><td rowspan="3">Section 1 Part A: Mathematics</td></tr>
<tr><td>Chemistry questions</td><td>Section 2 Chemistry</td><td>Section 1 Part C: Chemistry</td></tr>
<tr><td>Physics questions</td><td>Section 2 Physics</td><td>Section 1 Part B: Physics<br>Section 1 Part E: Advanced Mathematics and Advanced Physics</td></tr>
</table>

## Biology

**1 Biodiversity**

**1.1** the variety of life, both past and present, is extensive, but the biochemical basis of life is similar for all living things

**1.2** biodiversity refers to the variety and complexity of life and may be considered at different levels

**1.3** biodiversity can be measured, for example within a habitat or at the genetic level

**1.4** classification is a means of organising the variety of life based on relationships between organisms and is built around the concept of species

**1.5** originally classification systems were based on observable features but more recent approaches draw on a wider range of evidence to clarify relationships between organisms

**1.6** adaptations of organisms to their environments can be behavioural, physiological and anatomical

**1.7** adaptation and selection are major factors in evolution and make a significant contribution to the diversity of living organisms

**2 Exchange and transport**

**2.1** organisms need to exchange substances selectively with their environment and this takes place at exchange surfaces

**2.2** factors such as size or metabolic rate affect the requirements of organisms and this gives rise to adaptations such as specialised exchange surfaces and mass transport systems

**2.3** substances are exchanged by passive or active transport across exchange surfaces

**2.4** the structure of the plasma membrane enables control of the passage of substances into and out of cells

**3 Cells**

**3.1** the cell theory is a unifying concept in biology

**3.2** prokaryotic and eukaryotic cells can be distinguished on the basis of their structure and ultrastructure

**3.3** in complex multicellular organisms cells are organised into tissues, tissues into organs, and organs into systems

**3.4** during the cell cycle genetic information is copied and passed to daughter cells

**3.5** daughter cells formed during mitosis have identical copies of genes while cells formed during meiosis are not genetically identical

**4 Biological molecules**

**4.1** biological molecules are often polymers and are based on a small number of chemical elements

**4.2** in living organisms nucleic acids (DNA and RNA), carbohydrates, proteins, lipids, inorganic ions and water all have important roles and functions related to their properties

**4.3** the sequence of bases in the DNA molecule determines the structure of proteins, including enzymes

**4.4** enzymes catalyse the reactions that determine structures and functions from cellular to whole-organism level

**4.5** enzymes are proteins with a mechanism of action and other properties determined by their tertiary structure

**4.6** enzymes catalyse a wide range of intracellular reactions as well as extracellular ones

**4.7** ATP provides the immediate source of energy for biological processes

# Chemistry

**1 Formulae, equations and amounts of substance**

**1.1** empirical and molecular formulae

**1.2** balanced chemical equations (full and ionic)

**1.3** the Avogadro constant and the amount of substance (mole)

**1.4** relative atomic mass and relative isotopic mass, calculation of reacting masses, mole concentrations, volumes of gases, percent yields and atom economies

**1.5** simple acid–base titrations

**2 Atomic structure**

**2.1** structure and electronic configuration of atoms (up to Z = 36) in terms of main energy levels and s, p and d orbitals

**2.2** ions and isotopes; use of mass spectrometry in determining relative atomic mass and relative abundance of isotopes

**3 Bonding and structure**

**3.1** interpretation of ionic and covalent bonding in terms of electron arrangements. Examples of simple covalent, giant covalent, ionic and metallic structures

**3.2** permanent and induced dipole–dipole interactions between molecules, including hydrogen bonding. Electronegativity and its application to bond type. Interpretation of the physical properties of materials in terms of structure and bonding

**3.3** shapes of simple molecules and ions with up to six outer pairs of electrons (any combination of bonding pairs and lone pairs). Interpretation in terms of electron pair repulsion theory

**4 Energetics**

**4.1** enthalpy changes, including standard enthalpy changes of reaction, formation and combustion. Average bond enthalpies

**4.2** use of Hess's law to calculate enthalpy changes

**5 Kinetics**

**5.1** a qualitative understanding of collision theory. Activation energy and its relationship to the qualitative effect of temperature changes on rate of reaction. Boltzmann distribution

**5.2** the role of catalysts in providing alternative routes of lower activation energy

**6 Equilibria**

**6.1** the dynamic nature of equilibria. For homogeneous reactions, the qualitative effects of temperature, pressure and concentration changes on the position of equilibrium

**6.2** equilibrium constants, $K_c$

**7 Redox**

**7.1** oxidation states and their calculation

**7.2** oxidation and reduction as electron transfer, applied to reactions of s, p and d block elements

**8 Inorganic chemistry and the periodic table**

**8.1** the organisation of elements according to their proton number and electronic structures. Classification of elements into s, p and d blocks

**8.2** the characteristic reactions of the elements and compounds of a metallic group and a non-metallic group. Trends in properties of elements and compounds within these groups

**8.3** trends in properties of elements across a period including:

**a.** melting point

**b.** ionisation energy

**9 Organic chemistry**

**9.1** functional groups. Structural isomers and stereoisomers (to include geometric (E– Z) isomerism as a result of restricted rotation about a carbon–carbon double bond)

**9.2** reactions classified as addition, elimination, substitution, oxidation, addition polymerisation

**9.3** mechanisms classified as radical substitution, electrophilic addition, nucleophilic substitution

**9.4** single and double covalent bonds, bond polarity and bond enthalpy as factors influencing reactivity, illustrated by reference to appropriate reactions

**9.5** organic synthesis, including characteristic reactions of alkanes, alkenes, halogenoalkanes, alcohols

**9.6** modern analytical techniques

**9.7** the use of mass spectrometry, infrared spectroscopy, in analysis, including techniques for the elucidation of structure

# Physics

## 1 Vectors and scalars

**1.1** the distinction between vector and scalar quantities

**1.2** resolution of vectors into two components at right angles

**1.3** addition rule for two vectors

**1.4** calculations for two perpendicular vectors

## 2 Mechanics

**2.1** kinematics:

- **a.** use of kinematic equations in 1-dimension with constant velocity or acceleration
- **b.** graphical representation of accelerated motion
- **c.** interpretation of velocity-time and displacement-time graphs

**2.2** dynamics:

- **a.** use of $F = ma$ when mass is constant
- **b.** 1- and 2-dimensional motion under constant force
- **c.** independent effect of perpendicular components with uniform acceleration, projectile motion

**2.3** energy:

- **a.** calculation of work done for constant forces, including force not along the line of motion
- **b.** calculation of exchanges between gravitational potential energy and kinetic energy
- **c.** principle of conservation of energy

**2.4** momentum:

- **a.** definition
- **b.** principle of conservation of momentum
- **c.** calculations for one-dimensional problems

## 3 Mechanical properties of matter

**3.1** stress, strain, Young's modulus

**3.2** force-extension graphs, energy stored

## 4 Electric circuits

**4.1** current:

- **a.** electric current as rate of flow of charge, $I = \Delta q/\Delta t$

**4.2** emf and potential difference:

**a.** definition of emf and concept of internal resistance

**b.** potential difference in terms of energy transfer

**4.3** resistance:

**a.** definition

**b.** resistivity

**c.** Ohm's law

**4.4** DC circuits:

**a.** conservation of charge and energy in circuits

**b.** relationships between currents, voltages and resistances in series and parallel circuits

**c.** power dissipated

**d.** potential divider circuits

**5 Waves**

**5.1** qualitative treatment of polarisation and diffraction

**5.2** path difference, phase and coherence, interference

**5.3** graphical treatment of superposition and stationary waves

**6 Quantum and nuclear physics**

**6.1** photons and particles

**6.2** photon model to explain observable phenomena

**6.3** evidence supporting the photon model

**6.4** wave-particle duality, particle diffraction

# Appendix 3: Guidelines for the use of calculators

Where the use of a calculator is allowed, candidates are responsible for making sure that their calculators meet the regulations below.

**Candidates must be told these regulations beforehand.**

**Calculators must be:**

- of a size suitable for use on the desk
- either battery or solar powered
- free of lids, cases and covers which have printed instructions or formulas.

**Calculators must not:**

- be designed or adapted to offer any of these facilities:
  - language translators
  - symbolic algebra manipulation
  - symbolic differentiation or integration
  - communication with other machines or the internet
- be borrowed from another candidate during an examination for any reason*
- have retrievable information stored in them – this includes:
  - databanks
  - dictionaries
  - mathematical formulas
  - text.

**The candidate is responsible for the following:**

- the calculator's power supply
- the calculator's working condition
- clearing anything stored in the calculator.

**Advice:*** An invigilator may give a candidate a replacement calculator.

**Candidates must place their calculators on the floor under their desks in sight of the invigilator(s) for Section 1, the non-calculator section of the assessment.**

# Appendix 4: Example questions

In the following questions, the correct answer has been underlined.

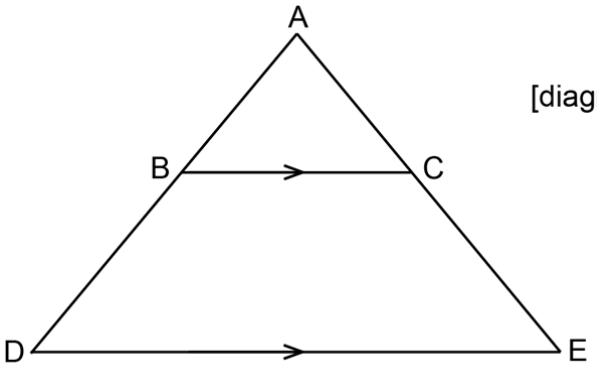
## Section 1

### Mathematics

**1** A shape is formed by drawing a triangle ABC inside the triangle ADE.

BC is parallel to DE.

AB = $4$ cm  BC = $x$ cm  DE = $x + 3$ cm  DB = $x - 4$ cm




[diagram not to scale]

Calculate the length of DE.

**A** $5$ cm

**B** $7$ cm

**<u>C</u>** $9$ cm

**D** $4 + 2\sqrt{7}$ cm

**E** $7 + 2\sqrt{7}$ cm

## Physics

**1** A ball is thrown vertically upwards and leaves the thrower's hand with a speed of 12 m / s. It can be assumed that all of the initial kinetic energy of the ball has been converted into gravitational potential energy when the ball reaches its highest point. Take the value of the gravitational field strength *g* to be 10 N / kg.

To what height does the ball rise?

**A** 7.2 m

**B** 14.4 m

**C** 24 m

**D** 60 m

**E** 120 m

## Chemistry

**1** By using standard techniques to balance chemical equations and ensuring that the net charge is equal on both sides, find the correct value for '**e**' in the balanced equation below:

**a** $C_2H_4O(aq)$ + $Cr_2O_7^{2-}(aq)$ + **b** $H^+(aq) \rightarrow$ **c** $C_2H_4O_2(aq)$ + **d** $Cr^{3+}(aq)$ + **e** $H_2O(l)$

**A** 1

**B** 2

**C** 4

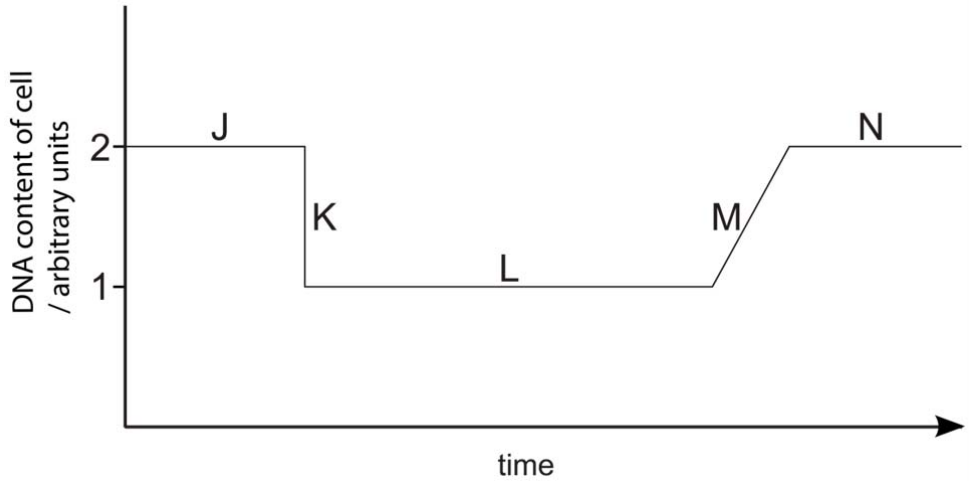
**D** 6

**E** 8

## Biology

**1** Before a cell can divide by mitosis, DNA synthesis has to take place. Following DNA synthesis, the DNA is separated into each half of the cell and then the cell divides.

The graph below shows the DNA content per cell over a period of time.




Which of the letters on the graph represent the sequence of the three events described above?

| | *cell divides* | *DNA synthesis* | *DNA separates* |
|---|---|---|---|
| **A** | J | K | L |
| **B** | J | L | M |
| **C** | K | L | M |
| **D** | K | M | N |
| **E** | L | M | N |
| **F** | L | M | J |
| **G** | M | N | J |
| **H** | M | N | K |

## Advanced Mathematics and Advanced Physics

**1** A particle of weight 5.0 N is held in position by two light ropes.

One of the ropes makes an angle of 60° with the upward vertical, the other is horizontal.

What is the tension in the horizontal rope?

**A** $5.0\sqrt{3}$ N

**B** $1.25\sqrt{3}$ N

**C** $10\sqrt{3}$ N

**D** 10 N

**E** 5 N

**2** What is the smallest possible value of $\int_0^1 (x-a)^2\,dx$ as $a$ varies?

**A** $\frac{1}{12}$

**B** $\frac{1}{3}$

**C** $\frac{1}{2}$

**D** $\frac{7}{12}$

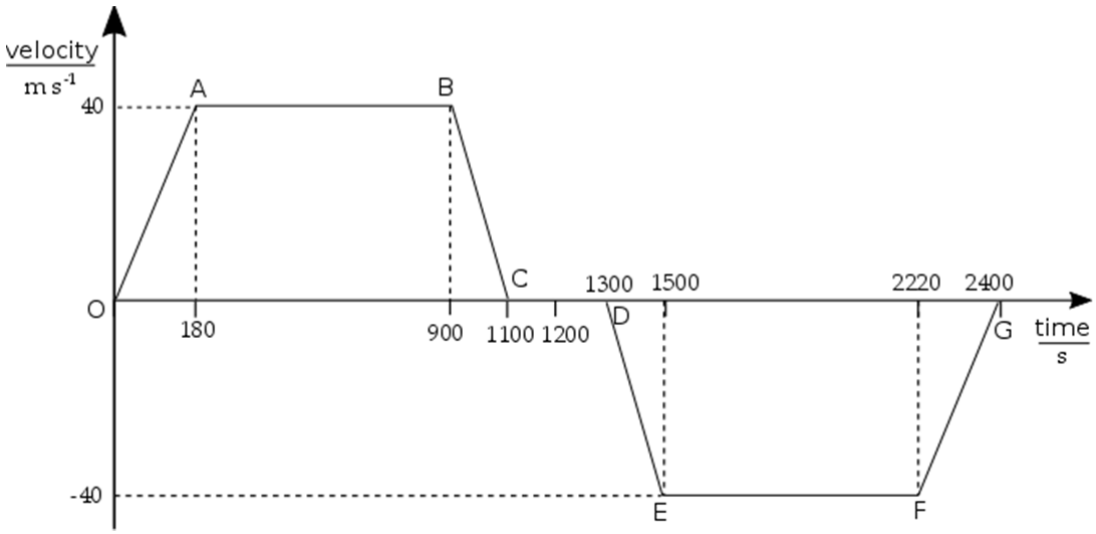
**E** $2$

# Section 2

## Physics

### Question 1

A train of mass 10 000 kg travels from a station on a straight, horizontal track. Its velocity, v(t), as a function of time is shown in the graph.




a) Calculate how far from the station the train is after 40 minutes. **[4 marks]**

b) Find an equation for the velocity of the train between B and C as a function of time. **[4 marks]**

c) Calculate

$$\int_{1300}^{1500} v(t)\,dt$$

**[4 marks]**

What quantity does this number represent? **[2 marks]**

d) Calculate the force exerted on the train when t = 1000 s. How does this force arise? **[3 marks]**

e) Calculate the mechanical power delivered by the train's engine when t = 90 s, neglecting the effects of air resistance. **[4 marks]**

f) Make an annotated plot of the position and acceleration of the train as a function of time over the range t = 0 s to t = 2400 s. **[4 marks]**

## Chemistry

### Question 1

a) There are two compounds with the formula $C_3H_6$. Write out the structures of these molecules as a displayed formula and as a skeletal formula. Give the names of the two compounds and identify the particular class of compounds each belongs to. **[4 marks]**

b) Like every other member in its class, one isomer of $C_3H_6$, isomer **A**, reacts rapidly with bromine to form a single product, **F**. Draw the structure of **A** as a skeletal formula and also the structure of the product formed when **A** reacts with bromine. **[3 marks]**

c) The second isomer of $C_3H_6$, isomer **B**, has a number of unique properties. The other members in the same class of compounds only react with bromine in the presence of light and form HBr as a side product. However, **B** reacts with bromine in the absence of light (but much less rapidly than **A**) and forms a single compound **G**. **F** and **G** are isomers. Draw the structures of **B** and **G** as skeletal formulae. **[4 marks]**

d) The table below gives values of the standard enthalpies of combustion, $\Delta_c H^o$ , of **A**, **B**, carbon (as graphite) and hydrogen.

| | **A** | **B** | C(s) (graphite) | $H_2$(g) |
|---|---|---|---|---|
| $\Delta_c H^o$ / kJ mol$^{-1}$ | −2058 | −2091 | −393.5 | −241.8 |

(i) Give the balanced chemical equation for the complete combustion of $C_3H_6$. **[2 marks]**

(ii) Calculate the standard enthalpy of formation, $\Delta_f H^o$, of **A**. **[3 marks]**

(iii) Calculate the standard enthalpy of formation of **B**. **[3 marks]**

(iv) Calculate the standard enthalpy change for the reaction **B** → **A**.
Comment on the value you obtain. **[2 marks]**

e) The standard enthalpy of combustion of $C_6H_{12}$ is −3920 kJ mol$^{-1}$. Using this value and the corresponding value for **B**, calculate the average contribution $\Delta_c H^o$ per $CH_2$ group for the two compounds. Comment on your result. **[4 marks]**

# Biology

## Question 1

Look at the following table.

| | 320 | | | | | | | | | | 330 | | | | | | | | | | 340 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Organism 1 | G | C | C | T | A | G | G | C | A | T | T | A | C | G | C | T | A | C | G | T | C | G | C | A | T | T | A | T | A | C |
| Organism 2 | G | C | T | A | A | G | G | C | A | C | T | A | C | G | C | T | A | C | G | T | C | G | C | T | T | A | A | T | A | G |
| Organism 3 | G | C | T | A | A | G | C | A | C | T | A | C | G | C | T | A | C | G | T | C | G | C | T | T | A | A | T | A | G | C |
| Organism 4 | G | C | T | A | A | G | G | C | A | C | T | A | C | G | C | T | A | C | G | T | C | G | C | A | T | T | A | T | A | C |
| Organism 5 | G | C | C | A | A | G | G | C | A | C | T | A | C | G | C | T | A | C | G | T | C | G | C | A | T | T | A | T | A | C |
| Organism 6 | G | C | T | A | A | G | G | C | A | C | T | A | C | G | C | T | A | C | G | T | C | G | C | T | T | T | A | T | A | C |
| Organism 7 | G | C | T | A | A | G | A | G | A | C | T | A | C | G | G | A | A | C | G | C | C | G | C | T | T | A | A | T | A | G |

a) What does each horizontal line represent? **[1 mark]**

b) If the molecules represented above are transcribed, how would the sequences of the transcripts differ from the original sequences? (Note that you do not need to write out all of the transcripts.) **[3 marks]**

c) Which of the sequences is least likely to lead to a functional part of a protein, and why? **[3 marks]**

d) Each organism in the table belongs to a different species. Based on the sequences, state which organisms are i) the most related to each other, and ii) the least related to each other. **[4 marks]**

e) If organisms 1 – 6 are all Eukaryotes, which Domain(s) of life could organism 7 belong to? **[2 marks]**

f) Discuss how the differences in these sequences might have arisen, and the possible evolutionary consequences of this variation. **[12 marks]**