What the ESAT assesses, and what to watch

This is the content of the test, module by module, written so that a student can revise from it: each line says what you must be able to do. What the test covers is not hard to find out; it is simply scattered, and phrased for the people who administer the test rather than for the person sitting it. This puts it in one place, in order, in the words a candidate would use. Where a line carries a note in smaller type, that is the slip candidates most often make on it.

How the test is put together. Mathematics 1 is compulsory. You then sit further modules chosen from Mathematics 2, Physics, Chemistry and Biology according to what your course asks for, and every module is 27 multiple-choice questions in 40 minutes. Questions offer between four and eight options, one of which is correct. There is no negative marking and no calculator.

Deadlines, and what to watch. The dates change every year and are published only by the test provider, so read them there and put them in a diary the day you do. The shape does not change: you register yourself, on the provider's site, some weeks before the sitting; registration closes well before test day and there is no late entry; the test sits once in the autumn, before university decisions are made; your result goes to the universities you name at registration. If you need access arrangements, they are requested at registration with evidence, not on the day. On the day you need photographic identification that matches the name you registered under. The three things that cost candidates a sitting are registering late, registering under a name that does not match their identification, and assuming a school will register for them.

Mathematics 1

M1 · Units and compound measures

- Work with quantities in the standard units for mass, length, time and money, and in the standard units used for other kinds of measure.
- Calculate and interpret compound measures: speed, pay rates, price per unit, density and pressure. A compound unit tells you the calculation: km/h means kilometres divided by hours.
- Carry decimal values through these unit calculations whenever the situation calls for them. Decimal hours are not minutes: 2.25 hours is 2 h 15 min.
- Convert between related units of time, length, area, volume or capacity and mass, and between compound units such as speed, pay rates, prices, density and pressure, whether the quantities are plain numbers or algebraic expressions. Area conversions square the factor and volume conversions cube it.

M2 · Number

- Put a mixed list of whole numbers, decimals and fractions, negatives included, into size order. Negative numbers reverse the order: minus seven is less than minus three.
- Read and use the comparison symbols correctly: equals, not equal to, less than, greater than, less than or equal to, and greater than or equal to, each the right way round. The open end of the inequality sign faces the larger number.
- Add, subtract, multiply and divide whole numbers, decimals, proper and improper fractions and mixed numbers, with negatives in the mix as well as positives. Convert mixed numbers to improper fractions before multiplying or dividing.
- Know and use the language of primes, factors (also called divisors), multiples, common factors and common multiples. Find a highest common factor and a lowest common multiple, and write a number as a product of its prime factors. HCF uses the lowest power of each shared prime, LCM the highest.
- Strip out common factors before you multiply or divide, so that a calculation or an algebraic expression becomes shorter to handle. Cancel only factors of the whole top and bottom, never single terms.
- Apply the agreed order of operations: brackets first, then powers, then multiplication and division, then addition and subtraction. Multiplication and division share a rank, so work them left to right.
- List possibilities in an organised way so that none is missed or counted twice, and use the multiplication principle: m ways for one choice and n ways for a second give m times n ways for the pair. Multiply the counts when choices are made together, add when they are alternatives.
- Know what square, cube, square root and cube root mean, and remember that every positive number has two square roots, one positive and one negative. The root sign on its own means the positive root only
- Apply the rules of indices to tidy up numerical expressions, multiplying and dividing powers whose exponents may be whole, fractional or negative. A negative index means take the reciprocal, not make the answer negative
- Read a number given in standard form, put several such numbers in order of size, and do arithmetic with them. Compare the powers of ten first, then the leading digits
- Know the shape of standard form: a number from 1 up to but not including 10, multiplied by a power of ten whose exponent is an integer, negative ones included. Adjust the power whenever the leading part drifts outside 1 to 10
- Turn a terminating decimal into a percentage or a fraction and back again, in any direction between the three forms. Simplify the fraction fully: 0.35 is 7/20, not 35/100
- Write a recurring decimal as an exact fraction, and turn a fraction back into the recurring decimal it produces. Multiply by the power of ten that matches the repeating block
- Switch freely between fraction, decimal and percentage forms in the middle of a calculation, choosing whichever makes the arithmetic easiest. A percentage is out of 100, so 12.5% is 0.125
- Recognise when two fractions stand for the same value, and produce an equivalent fraction by scaling numerator and denominator by the same factor. Adding the same number to top and bottom is not equivalence
- Calculate exactly, leaving answers in terms of fractions, surds or multiples of pi rather than decimals. Simplify a surd by taking out any square factor, so root 12 becomes 2 root 3, and clear a surd from a denominator. Rationalise by multiplying top and bottom, never the denominator alone
- Find the lower and upper bounds between which a rounded measurement must lie, and carry those bounds through a calculation, including in a word problem. For a quotient, the upper bound divides by the lower bound
- Round a number or a measurement to a sensible precision, whether that is a stated count of decimal places or of significant figures. Leading zeros are not significant: 0.0305 has three significant figures

- Write the interval a value could have lain in before it was rounded or truncated, using inequality signs, for instance 2.45 up to but not including 2.55 for a value that rounded to 2.5. The top end takes a strict less-than, the bottom end a less-than-or-equal
- Round the numbers in a calculation to convenient values and work out a rough answer for it. Round each number before calculating, not the final answer
- Estimate the value of an expression containing pi or a surd by swapping each for a nearby simple number. Take pi as about 3 and root 2 as about 1.4

M3 · Ratio and proportion

- Use a scale factor to move between lengths on a scale drawing or map and the real lengths they represent, in either direction. Match units before applying the scale: cm on the map, km on the ground
- Write one amount as a fraction of a second amount, whether the result comes out below 1 or above it. Put both amounts in the same units before forming the fraction
- Read and write a ratio in the colon form, such as 3 : 5, and know what each part of it stands for. Order matters: 3 : 5 is not 5 : 3
- Split an amount into two or more shares in a stated ratio, finding the size of each share. Divide by the total of the ratio parts, not by their count
- Given the two pieces an amount has been split into, write the split as a ratio. Give the ratio of part to part, not part to whole
- Use ratio in practical settings: converting between units or currencies, comparing amounts, scaling up or down, mixing components, and describing concentrations. Mixing 1 : 4 gives five parts in total, not four
- When one quantity is a fixed multiple of another, capture that link as a ratio or as a fraction. A ratio of 2 : 5 means multiply by 2.5, not add 3
- Turn a ratio into the fraction of the whole that each part takes, and recognise that two quantities kept in a fixed ratio are joined by a straight line through the origin, y = kx. In 2:3 the first part is 2/5 of the whole, not 2/3
- Spot the fraction hidden in a ratio problem, whether one part as a fraction of another or as a fraction of the whole, and switch between ratio and fraction to reach the answer. A fraction compares part to whole; a ratio compares part to part
- Know that a percentage means so many parts out of a hundred. Write a percentage, or a percentage change, as a decimal or a fraction and apply it as a multiplier: up 15% means multiply by 1.15, down 15% means multiply by 0.85. A 20% fall followed by a 20% rise does not restore the original
- Give one amount as a percentage of another: divide the first by the second, then multiply by a hundred. Divide by the quantity you are comparing against, not the other way round
- Recognise when one quantity is a fixed multiple of another, y = kx, and when their product is fixed, y = k/x, and write the matching equation from the values you are given. Inverse proportion keeps the product constant, not the sum
- Tell direct from inverse proportion by the shape of a graph, a straight line through the origin for one and a curve that never touches either axis for the other, and read the constant off it. A straight line that misses the origin is not direct proportion
- Build the proportion equation from the information in a question, including one where a quantity varies with a power of another such as its square or its square root, then use it to find missing values and say what its constant means in context. Find the constant from the given pair before answering anything else
- Write how two lengths, two areas or two volumes compare as a ratio in its simplest form. Convert to the same units before you write the ratio
- Connect ratio to similar shapes: matching sides of similar figures are all in one ratio, so a ratio found from one pair gives every other pair. Pair corresponding sides, not any two sides that happen to be given
- Treat sine, cosine and tangent as side ratios shared by every similar right-angled triangle, and use scale factors between similar shapes: k for lengths, k squared for areas, k cubed for volumes. Area scales by the square of the length factor, volume by the cube
- Model something that grows or shrinks by a fixed percentage each step as a multiplier raised to a power, solve for the unknown, and say what the answer means in the situation. Repeated percentage change multiplies each step; do not add the percentages
- Handle compound interest, where each period's interest is added before the next period's is worked out, and follow any rule that feeds each result back in to produce the next one. Compound interest builds on the new total, not the starting sum

M4 · Algebra

- Read and write algebra in its standard shorthand, so that ab stands for a multiplied by b and every compressed form is understood before you work with it. Letters written side by side are multiplied, not added

- Know that 3y is the shorthand for adding three lots of y together, or for three multiplied by y. 3y means 3 times y, not 3 plus y
- Know that a squared is the shorthand for a multiplied by itself. a squared is a times a, not 2a
- Know that a cubed is the shorthand for three copies of a multiplied together. a cubed is not 3a: the power counts factors, not terms
- Know that a squared b is the shorthand for a times a times b: the square belongs to a alone. The index applies only to the letter it sits on, not to b
- Apply the rules for powers to algebraic terms: add the indices when you multiply, subtract them when you divide, and do this with whole-number, fractional and negative indices alike. Index laws need the same base; x squared times y cubed does not combine
- Put given numbers into an expression or a formula, including one taken from science, and evaluate it correctly. Substituting a negative number needs brackets: the square of minus 3 is 9
- Know the difference between an expression, an equation, a formula, an identity, an inequality, a term and a factor, and use each word correctly. An identity holds for every value; an equation only for some
- Gather terms that match, multiply out a bracket by the single term in front of it, pull a shared factor out of an expression, and multiply out a product of two or more brackets such as (x + 2)(x - 3). A minus sign before a bracket flips every sign inside it
- Turn a quadratic whose x^2 coefficient is 1, so $x^2 + bx + c$, back into a product of two brackets. The two numbers must multiply to c and add to b, signs included
- Spot one square subtracted from another, whether $x^2 - 9$ or $4x^2 - 25$, and write it as (a + b)(a - b). A sum of two squares does not factorise this way
- Factorise a quadratic whose x^2 coefficient is not 1, so $ax^2 + bx + c$, into two brackets whose x terms may carry coefficients of their own. The number pair now multiplies to a times c, not to c
- Tidy an expression that mixes added terms, multiplied terms and powers into its simplest form. x times x is x^2, but x plus x is 2x
- Apply the index laws to algebraic terms: add the powers when multiplying like bases, subtract them when dividing, and multiply them when raising a power to a power. Same base only: x^2 times y^3 does not combine
- Reduce an algebraic fraction by cancelling a factor common to top and bottom, factorising first when the shared factor is not yet visible. Cancel whole factors only, never a single term inside a sum
- Add, subtract, multiply and divide algebraic fractions. Adding needs a common denominator; multiplying does not
- Rewrite a formula so that a different letter stands alone on one side. If the new subject appears twice, gather its terms and factorise it out
- Tell apart an equation, true only for particular values of the letter, from an identity, true whatever value the letter takes. The three-bar sign ≡ marks an identity: it holds for every value
- Prove two expressions are the same by rewriting one step by step until it matches the other. Checking one or two values is not a proof
- Plot and read off points with any mix of positive and negative x and y values. The x coordinate comes first: along before up
- Read off the gradient and the intercepts of a straight line y = mx + c, from a sketch or from the equation, and explain what each one means. Get y on its own first, or the gradient you read is wrong
- Spot when two lines are parallel, sharing one gradient, and when they are perpendicular, their gradients multiplying to give -1. A perpendicular gradient is the negative reciprocal, not just the negative
- From the graph of a quadratic, read off where it crosses the x axis, where it cuts the y axis and where it turns, and say what each of those points means. The turning point sits midway between the roots, not at the y intercept
- Find the roots by solving the quadratic, and find the turning point by writing it in completed square form and reading off the vertex. From $(x + p)^2 + q$ the vertex is (-p, q), sign flipped
- Recognise a straight line graph, sketch one from its equation, and read what it shows. x = 3 is a vertical line, not a horizontal one
- Recognise the parabola of a quadratic, sketch it from its equation, and interpret its features. A negative x^2 coefficient turns the parabola upside down
- Recognise the S-shaped curve of a simple cubic such as $y = x^3$, sketch it, and interpret its graph. A cubic's two ends point opposite ways, one up and one down
- Recognise and sketch y = 1/x, two branches in opposite quadrants that approach the axes without touching them, and read what the graph shows. There is no point at x = 0. The curve never meets either axis: no root, no y intercept
- Recognise the exponential curve y = k^x, where k is a positive constant, sketch it, and interpret its graph. Every y = k^x graph passes through (0, 1), since $k^0 = 1$

- Read a graph set in a real situation, whether reciprocal, exponential or of an unfamiliar shape, and use it to get an approximate answer, for instance to a simple problem about motion. Check what each axis measures before reading a value off the curve.
- Find, exactly or by estimating, the gradient of a graph and the area between the graph and the horizontal axis. For a curve, the gradient at a point is that of the tangent there.
- Do the same for quadratic and other curved graphs, and say what the gradient or area means in context: speed on a distance-time graph, distance covered on a speed-time graph, or a rate or total on a graph about money. Area under a speed-time graph is distance; its gradient is acceleration, not speed.
- Turn a problem into a simple equation, then solve it either by algebra or by drawing and reading a graph. Say which coordinate of the crossing point the question actually wants.
- Solve a pair of simultaneous equations in two unknowns, by algebra or by finding where their graphs cross. Substitute your pair back into both equations, not just one.
- Be ready for a pair in which one equation is linear and the other quadratic: substitute the linear one into the quadratic and expect up to two solution pairs. Each x-value needs its own y-value; pair them, never mix them.
- Find the values of the unknown that make a quadratic equation true. A quadratic can have two, one or no real solutions: give them all.
- When the equation is not already set equal to zero, rearrange it so it is, then solve by whichever method fits: factorising, completing the square, or the quadratic formula. Only factorise once one side is zero: $(x+1)(x+2)=6$ tells you nothing yet.
- Memorise the quadratic formula: x equals minus b, plus or minus the square root of b squared minus 4ac, all divided by 2a. The whole of minus b plus or minus the root sits over 2a.
- Solve a linear inequality, whether it involves one variable or two. Multiplying or dividing by a negative flips the inequality sign.
- Show the set of values that satisfy an inequality in three ways: marked on a number line, shaded on a graph, or described in words. An open circle means the endpoint is excluded; a filled one includes it.
- Write out the terms of a sequence from either kind of rule: one that tells you how to get each term from the one before, or one that gives any term straight from its position. The first term has position 1, not 0, when you substitute.
- Find a formula for the nth term of a sequence whose terms change by the same amount each step, and of one whose second differences are constant. Constant second difference d gives a leading coefficient of d over 2.

M5 · Geometry

- Know and use the standard words and symbols of geometry: point and line, line segment, edge and vertex, plane, parallel and perpendicular lines, right angle, and an angle subtended at a point. Perpendicular lines meet at a right angle; crossing alone is not enough.
- Recall and use the angle facts: angles round a point total 360 degrees, angles along a straight line total 180 degrees, perpendicular lines meet at 90 degrees, and vertically opposite angles are equal. Only vertically opposite angles are equal; the neighbours add to 180 degrees.
- Understand and use the angle facts for a pair of parallel lines cut by another line, for lines that intersect, and for the angles inside a triangle or a quadrilateral. Work out and use the total of the interior angles of any polygon, and the total of its exterior angles. Alternate and corresponding angles are equal; co-interior angles add to 180 degrees.
- Know how each special quadrilateral is defined, derive its properties from that definition, and use them to solve problems.
- Cover all six named shapes: the square, the rectangle, the parallelogram, the trapezium, the kite and the rhombus. Diagonals: equal in a rectangle, perpendicular in a rhombus, both in a square.
- Do the same for the kinds of triangle and for other plane shapes: start from the definition, derive the properties that follow, and use them in problems, naming each shape and property correctly.
- Know the four tests that prove two triangles congruent, SSS, SAS, ASA and RHS, and use them to show or decide that two triangles are identical in shape and size.
- Use what you know about angles, congruent and similar triangles, and the special quadrilaterals to find unknown angles and lengths, or to justify a claim about them. Similar triangles give equal angles and proportional sides, not equal sides.
- Recognise when two shapes are congruent or similar, explain why, and draw a congruent or similar copy of a given shape. Congruent means identical in size as well as shape; similar allows scaling.
- Carry out translations, rotations, reflections and enlargements on a coordinate grid, describe each one fully, and use them to show that two shapes are congruent or similar. A full description of a rotation needs centre, angle and direction.

- Enlarge a shape using a scale factor between 0 and 1, which makes it smaller, or a negative scale factor, which puts the image on the other side of the centre, rotated through a half turn. Do not draw a negative enlargement on the same side as the object.
- Use Pythagoras' theorem, $a^2 + b^2 = c^2$, to find a missing side of a right-angled triangle, and extend it to three dimensions, applying it twice to reach lengths such as the long diagonal of a cuboid. The hypotenuse is opposite the right angle: subtract when finding a shorter side.
- Know what each part of a circle is called and pick it out on a diagram: centre, radius, diameter, circumference, chord, arc, sector, segment and tangent. Sector: between two radii. Segment: cut off by a chord.
- Call the smaller of the two arcs, sectors or segments the minor one and the larger the major one. For a major sector, use 360 minus the given angle.
- Use the standard circle theorems, the ones about angles, tangents, chords and radii, to find unknown angles and lengths in a circle diagram. A tangent and the radius to its point of contact meet at 90 degrees.
- Use the theorems to prove further results, starting from the fact that an arc subtends an angle at the centre equal to twice the angle it subtends at the circumference. Both angles must stand on the same arc before you double.
- Answer questions about shapes drawn on a coordinate grid, working from the coordinates of the vertices to find lengths, midpoints and areas, or the position of a missing vertex. Sketch the points before naming the shape; a tilted square looks like a diamond.
- Know the words face, surface, edge and vertex, and be able to say how many of each a cube, cuboid, prism, pyramid, cylinder, cone, sphere or hemisphere has. Count the base as a face; a square pyramid has five, not four.
- Read a plan, the view from directly above, and the front and side elevations of a solid, and deduce from them the shape of the solid. A plan shows the footprint only; height appears in the elevations.
- Convert between a length measured on a map or scale drawing and the real distance it stands for, using the scale whether it is given as a ratio or in words. A ratio scale gives centimetres on the ground; convert to kilometres afterwards.
- Find the area of a triangle, a parallelogram or a trapezium from its formula, taking the height at right angles to the base. The height is perpendicular to the base, not the slanted side.
- Find the volume of a cuboid or any other right prism as the area of the cross-section multiplied by the length. The cross-section is the face that stays the same along the length.
- Know that a circle's circumference is $2\pi r$, which is the same as πd, and pick whichever form matches the measurement you are given. With the diameter given, use πd; $2\pi d$ doubles the answer.
- Know that a circle's area is πr^2, and halve the diameter first if that is what the question gives you. Square the radius, not the diameter; using d gives four times the area.
- Know that a cylinder's volume is $\pi r^2 h$, the area of the circular end times the height. You need not memorise the formulae for spheres, pyramids or cones: any question needing one supplies it. Learn $\pi r^2 h$; do not rely on the question to supply it.
- Find the length of an arc or the area of a sector as the matching fraction, angle over 360, of the whole circumference or area, and reverse the working to recover the angle. Arc length uses the circumference, $2\pi r$; sector area uses πr^2.
- Spot congruent or similar shapes inside a diagram, match up the corresponding sides and angles, and use the match to find an unknown length or angle. Corresponding sides lie opposite equal angles, whichever way the shapes are turned.
- For similar shapes and solids with length scale factor k, areas scale by k^2 and volumes by k^3; work in either direction, from a given area or volume ratio back to the length ratio. A volume ratio of 8 means a length ratio of 2, not 8.
- Know sine, cosine and tangent as ratios of the sides of a right-angled triangle, and use them to find a missing side or a missing angle. Do the same in a general triangle or a solid shape wherever a right-angled triangle can be found inside it. Opposite and adjacent are named from the angle in use, not fixed
- Add and subtract vectors, multiply a vector by a number, and move between a vector drawn as an arrow and one written as a column. The vector from A to B is b minus a, not a minus b
- Express the lines in a figure as combinations of given vectors and reason from them to prove a geometric result, such as showing two lines are parallel. Collinear needs parallel vectors that also share a point, not parallel alone

M6 · Statistics

- Read and draw the displays used for data in categories: pie charts, bar charts, pictograms, frequency tables and two-way tables. A pie sector shows a share of the total, not a count
- Read and draw a vertical line chart for discrete data that has not been put into groups. Never join the tops of the lines: values between them do not exist
- Read and draw histograms for grouped or continuous data, with classes of equal width and with classes of different widths. With unequal widths the height is frequency density: area, not height, gives frequency

- Read and draw a cumulative frequency graph for grouped or continuous data, and be able to say which of these diagrams suits a given set of data. Plot cumulative frequency at the upper bound of each class, not the midpoint
- Find the mean, the median, the mode and the range of a list of raw values. Order the values first for the median; an even count averages the middle two
- For grouped data, pick out the class with the highest frequency. Answer with the class interval itself, not the frequency it holds
- From a grouped frequency table, estimate the mean with class midpoints, and estimate the median and the range. Be able to say why these are estimates: grouping hides the actual values. Use the midpoint of each class, not its upper bound, for the mean
- Plot and read a scatter graph of paired measurements, and describe what the pattern of points shows about the two variables.
- Say whether a scatter graph shows positive, negative or no correlation, and remember that a correlation on its own does not show that one variable causes the other. Strong correlation still proves nothing about cause; a third factor may drive both
- Draw a straight line by eye through a scatter of points so that it follows the trend, with the points spread evenly on either side. The line need not pass through the origin or through any point
- Use the line of best fit to estimate a value inside the range of the data, and to extend the apparent trend to a value outside it. Know that the second is less reliable, since nothing in the data shows the pattern continues beyond it. Reading beyond the data assumes the trend continues, which it may not

M7 · Probability

- Record how often each outcome of an experiment occurred in a table or a frequency tree, and read counts and proportions from it. A frequency tree holds counts at each branch, not probabilities
- Using the idea that a fair device gives random, equally likely results, work out how many times an outcome should turn up over a set number of trials. Expected frequency is probability times number of trials, not the probability itself
- Know that running the same experiment again may well give a different result, since each outcome is random. An expected frequency of 50 does not mean exactly 50 will occur
- Link the fraction of trials an outcome is expected to take up with its theoretical probability, and describe likelihood in proper terms on the scale from 0, impossible, to 1, certain. Relative frequency approaches the theoretical value only over many trials
- Use the fact that the probabilities of all the possible outcomes of an experiment add up to 1, for example to find a missing probability in a table. The rule needs every outcome listed; a partial list does not sum to 1
- Use the fact that when events cannot happen together and between them cover every possibility, their probabilities add up to 1. Overlapping events break the rule: their probabilities can total more than 1
- List every member of a set, or of a combination of sets, in an orderly way, choosing whichever of a table, a grid, a Venn diagram or a tree diagram fits the problem. The overlap is counted in both sets: adding the totals double counts it.
- You do not need formal set notation: do the work in words and with those diagrams, not with the symbols for union, intersection or complement.
- Set out every outcome of a single trial, or of two or more trials combined, where each outcome is equally likely, for example as a list or a grid. Two dice give 36 ordered outcomes, not 11 totals or 21 pairs.
- Read a probability off that space by counting the outcomes that fit the event and dividing by the total number of outcomes. Only divide by the total when every outcome is equally likely.
- Add the probabilities of two events that cannot both happen to get the chance of one or the other; multiply to get the chance of both, using for the second event its probability once the first has happened. Know what a conditional probability is: the chance of an event given that another has occurred. After drawing without replacement, the second fraction changes: do not reuse the first.
- Turn the probabilities into expected numbers out of a chosen total, lay them out in a two-way table, a tree diagram or a Venn diagram, and read a conditional probability as a fraction of the one group the condition picks out. Be able to say in words what that figure means. Divide by the total of the 'given' group, not the whole table.

Mathematics 2

MM1 · Algebra and functions

- Use the rules for multiplying and dividing powers and for raising a power to a power when the index is zero, negative or a fraction, not only a positive whole number, and read a fractional index as a root. A negative index means a reciprocal, not a negative answer.
- Handle square roots that are not whole numbers as exact quantities: add and subtract like roots, multiply and divide roots, and split the root of a product into a product of roots. Only products and quotients split into separate roots, never sums.
- Reduce an expression containing roots to its simplest form: take square factors out of a root, collect like roots, and clear a root from the bottom of a fraction by multiplying top and bottom by a suitable surd. For a denominator like $2-\sqrt{3}$, multiply by $2+\sqrt{3}$.
- Sketch the graph of a quadratic from its equation, and read from the equation or the graph which way it opens, where it meets the axes and where its turning point is. In $(x+p)^2+q$ the turning point is at $x=-p$, not p.
- Work out b^2-4ac and use its sign to say whether the quadratic has two distinct real roots, one repeated root or none, and so whether its graph crosses, touches or misses the x-axis.
- Solve a quadratic equation by factorising, by completing the square or by the formula, picking the method that suits the numbers in front of you. Rearrange to equal zero before factorising; dividing by x loses a root.
- Solve a pair of simultaneous equations exactly by rearranging one to give an unknown in terms of the other and substituting into the second, in particular when one equation is a straight line and the other is a quadratic. Pair each x with its own y; the answer is two points, not four.
- Find the set of values of x that satisfies an inequality, whether the expression is linear or quadratic, and give the answer as a single range or as two separate ranges. Dividing by a negative reverses the sign; sketch a quadratic before choosing the region.
- Multiply out brackets in a polynomial expression, including products of several brackets, and gather the terms of equal power so that the result is one tidy polynomial. $(x+3)^2$ has a middle term $6x$; it is not x^2+9.
- Factorise a polynomial, and divide one by a linear or a quadratic expression, including divisors such as $2x+1$ or $2x^2+3x+1$ whose leading coefficient is not one, to find the quotient and any remainder. Use the Factor Theorem to test for a factor and the Remainder Theorem to find a remainder without dividing. For factor $2x+1$, test $x=-\frac{1}{2}$, not $x=-1$.
- Know, without formal definitions, that a function sends each input to exactly one output, so several inputs may share an output but one input never has two. Many-to-one means several x for one y, not several y for one x.
- Recognise the functions that come up most often and know how each one behaves, including the shape of its graph and the values it can and cannot take.
- Know that $\sqrt{x}$ always means the positive square root, so $\sqrt{9}$ is 3 and never -3, and be familiar with the modulus function $|x|$, which makes a negative input positive and leaves a positive one alone.

MM2 · Sequences and series

- Work with a sequence whether it is defined by an expression for its general term or by a rule that produces each term from the one before, such as $x_{n+1}=f(x_n)$, and find terms of either kind. Substitute the previous term, not n, into the recurrence rule.
- Add the whole numbers from 1 to n in one step with n(n + 1)/2, and recognise this as the simplest arithmetic series, first term 1 and common difference 1. It starts at 1: subtract the early terms if the run begins later
- Add up the first n terms of a geometric sequence using a(1 - r^n)/(1 - r), and work backwards from a known total to find n, a or r. Count the terms: the power in the formula is n, not n - 1
- Find the limiting total of a geometric series that goes on for ever, a/(1 - r), when its terms shrink towards zero. Divide by 1 - r, not r - 1, or the sign comes out wrong
- Test whether a never-ending geometric series settles to a total at all: it does only when the ratio r lies strictly between -1 and 1, so state or apply that condition where a question turns on it. Negative ratios count too: it is the size of r, not its sign
- Expand (1 + x) raised to a positive whole-number power, and likewise a bracket of the shape (a + f(x)) to such a power where f(x) is something simple. Read and use n! and the nCr notation for the coefficients. Raise the whole term to the power: (2x)^3 is 8x^3, not 2x^3

MM3 · Coordinate geometry

- Write down a line's equation from its gradient m and any one point (x1, y1) on it: y - y1 equals m(x - x1). Substitute the point's coordinates for x1 and y1, not for x and y

- Work with a line in the general form ax + by + c set equal to zero, including reading its gradient from it. Decide whether two lines are parallel (same gradient) or perpendicular (gradients multiplying to -1), and find a line's equation from whatever you are told about it. In the general form the gradient is -a/b: the minus is easily dropped
- Read a circle's centre (a, b) and radius r straight from (x - a)^2 + (y - b)^2 = r^2, and write that equation down from a given centre and radius. The right-hand side is r squared, so 25 there means radius 5
- Recognise a circle written out in full as x^2 + y^2 plus terms in x, in y and a constant, all equal to zero, and complete the square in x and in y to recover its centre and radius. Halve the x and y coefficients when completing the square, then square that half
- Use the fact that a line from the centre meeting a chord at right angles cuts the chord in half, so the radius, half the chord and the centre's distance from the chord form a right-angled triangle. Use half the chord in Pythagoras with the radius, not the whole chord
- Use the fact that a tangent and the radius to its point of contact meet at a right angle, so the gradient of the tangent is the negative reciprocal of that of the radius. Take the radius gradient from centre to contact point, then flip and negate it

MM4 · Trigonometry

- Use the sine rule and the cosine rule to find missing sides and angles, and find a triangle's area as half ab sin C. Know that the sine rule can give two possible triangles when two sides and a non-included angle are known, and expect these problems in three dimensions as well as two. Sine gives two angles: check whether 180 minus your answer also fits
- Work in radians to find an arc's length as r times theta, a sector's area as half r squared theta, and a segment's area by taking the triangle away from the sector. These formulas need the angle in radians; a degree value gives nonsense
- Know the exact values of sin, cos and tan at 0, 30, 45, 60 and 90 degrees from memory, in surd form where needed. Do not swap the 30 and 60 degree values: sin 30 is one half
- Treat sin, cos and tan as functions that take any angle, negative or beyond 90 degrees included, not only as ratios inside a right-angled triangle. Sin and cos give a value for every angle; tan has none at 90 degrees or at any odd multiple of it. Sine and cosine never exceed 1 in size; tangent can be any value
- Sketch the graphs of sin, cos and tan and use their symmetry and their repeat: sin and cos repeat every 360 degrees and tan every 180, and the shapes give relations such as cos(-x) = cos x and sin(180 - x) = sin x. tan repeats every 180 degrees, not 360, with a break at 90
- Know that tan of an angle is its sine divided by its cosine, and swap between tan and sin over cos wherever that simplifies an equation or an identity. It is sine over cosine, not cosine over sine
- Know that sin squared plus cos squared of one angle equals 1, and use it to trade sin^2 for 1 - cos^2, or the reverse, when solving or simplifying. Replace sin^2 x by 1 - cos^2 x, not by 1 - cos x
- Find every solution of a simple trig equation inside a stated interval, using the identities above where they help, including equations in a multiple or shifted angle such as 2x + pi/3 and ones with sin or cos squared. Change the interval to match the bracket before listing solutions for 2x + pi/3

MM5 · Exponentials and logarithms

- Sketch y = a^x for a simple positive base a: it passes through (0, 1), rises when a is above 1, falls towards zero when a is between 0 and 1, and never crosses the x-axis. Every such graph passes through (0, 1), not the origin
- Convert between index form and log form: a raised to the power b equals c says the same thing as b equals the log of c to base a, so you can go either way. The exponent becomes the logarithm's value, not its base.
- Combine two logs with the same base that are being added into a single log of the product, and split the log of a product back into a sum. There is no rule for the log of a sum.
- Turn the difference of two logs to the same base into one log of a quotient, and split the log of a fraction back into a subtraction. Order matters: the log being subtracted goes in the denominator.
- Move a multiplier in front of a log inside as a power on the argument, and bring a power out as a multiplier. Know the special cases that come with the laws, including that the log of a to base a is one, because a to the power one is a. A power on the whole log, (log x)^k, is not k log x.
- Rewrite the log of a reciprocal as minus the log of the number itself, and rewrite minus the log of a number as the log of its reciprocal. A negative log means a reciprocal argument, not a negative argument.
- Solve an equation with the unknown in the exponent, a fixed base raised to some multiple of x equalling a number, and spot an equation that can be rewritten into that shape. log b divided by log a is not log of b over a.
- Do the algebra first when the equation is not yet in that shape: for instance, write 25 to the x as the square of 5 to the x, so the equation becomes a quadratic in that power. Solving for the substituted power is not the end: still find x.

MM6 · Differentiation

- Understand a derivative as the rate at which one quantity changes with respect to another, which on the graph is the tangent's gradient at that point. The rate of change at a point is f'(a), not f(a).
- Differentiate a derivative again to obtain the second derivative.
- Read and write both notations for a first derivative, dy/dx and f'(x), and for a second derivative, d^2y/dx^2 and f''(x), whichever form a question uses. In d^2y/dx^2 the 2 marks two differentiations, not a power.
- Differentiate any power of x, fractional and negative powers included, and expressions built by adding and subtracting such terms. Subtract one from a negative power too: x^-2 gives -2x^-3.
- Simplify first when an expression is not yet a sum of powers of x, for example by expanding a product or writing roots and fractions as powers, then differentiate term by term. Differentiating top and bottom of a fraction separately is wrong.
- Apply differentiation to find the gradient at a point, the equation of a tangent or a normal, and the stationary points of a curve, which here means maxima and minima only. Decide where a function is strictly increasing or strictly decreasing from the sign of its derivative, positive for increasing and negative for decreasing. A normal's gradient is minus the reciprocal of the tangent's, not just minus.

MM7 · Integration

- Link a definite integral to the region a curve encloses with an axis, and understand why the integral and the area can differ: where the curve dips below the axis the integral counts that part as negative, while an area is always positive. Integrating straight across an axis crossing cancels area; split at the roots.
- Integrate any power of x other than x to the minus one, both with limits and without, and expressions formed by adding or subtracting such terms. Divide by the new power, not the old, and remember the constant.
- Rewrite an expression as a sum of powers of x before integrating, for example by multiplying out a product or splitting a fraction into separate terms. A product cannot be integrated factor by factor: expand it first.
- Evaluate a definite integral between two limits by substituting the upper limit and then the lower limit into an antiderivative and subtracting the second from the first. Upper minus lower, and keep the sign when the lower value is negative.
- Know that the antiderivative you substitute into is any function whose derivative is the integrand, and see why this makes integration the reverse of differentiation. The constant of integration cancels in a definite integral; any antiderivative works.
- Add or subtract integrals that share the same limits by integrating the combined function, and join integrals of one function over ranges that meet end to end into a single integral across the whole range, allowing for a range that runs backwards. Reversing the limits reverses the sign of the integral.
- Estimate an area beneath a curve with the trapezium rule: divide the interval into strips of equal width and treat each strip's top edge as a straight line. With n strips there are n + 1 ordinates; the middle ones are doubled.
- Decide from the way the curve bends whether the trapezium rule gives too much or too little: the straight tops sit above a curve that bends upward, giving an overestimate, and below one that bends downward, giving an underestimate. Judge from how the curve bends, not from whether it rises or falls.
- Solve a differential equation in which dy/dx is given as a function of x alone, by integrating to find y. Include the constant of integration; a given point is what fixes it.

MM8 · Graphs and transformations

- Know the shape of each standard graph and sketch it from its equation: straight lines, quadratics and cubics, the modulus and square root functions, and the trigonometric, logarithmic and exponential ones. Exponential and log curves approach an axis but never touch it.
- Say how the curve y = f(x) shifts, stretches or reflects when it becomes y = af(x), y = f(x) + a, y = f(x + a) or y = f(ax), with a positive or negative, and when two or more of these are applied in turn. Read and use the notation f(g(x)) for one function applied after another. f(x + a) with positive a shifts the curve left, not right.
- Explain what changing m does to the line y = mx + c, and what changing c does. c is the y intercept, not where the line meets the x axis.
- Say how the parabola y = a(x + b)^2 + c changes when a, b or c is altered, including where its vertex ends up. The vertex sits at x = minus b, not at x = b.
- Differentiate, set the derivative equal to zero and solve to locate the maximum and minimum points of a curve; stationary points of inflexion are not required. Solving dy/dx = 0 gives only x; substitute back to get y.
- Use the sign of the derivative to decide over which ranges of x a curve is rising and over which it is falling. A curve is increasing where dy/dx is positive, whatever the sign of y.
- Find where a curve meets the axes by algebra: put x = 0 for the y intercept and solve y = 0 for the x intercepts. Solve y = 0 by factorising or the formula, never by reading a sketch.

- Know which numbers of real roots a polynomial of a given degree can have, for example a quadratic has none, one or two and a cubic has one, two or three. Every cubic has at least one real root; a quadratic may have none.
- Connect the algebra to the picture: a solution of $f(x) = 0$ is an x value where the curve $y = f(x)$ meets the x axis. A repeated root is where the curve touches the axis rather than crossing.
- Know that the points where two graphs cross are exactly the solutions of the pair of equations solved together, so counting crossings counts solutions. Where the curves merely touch, the simultaneous equations have a repeated solution.

Physics

P1 · Electricity

- Explain how rubbing two insulators together leaves each of them charged. Rubbing works on insulators because the charge cannot flow away again.
- State that an object becomes charged only by gaining or losing electrons: negative when it gains them, positive when it loses them. Electrons move, protons stay put: a positive charge is a shortage of electrons.
- State that two charges of the same sign push each other apart and two of opposite sign pull together. Attraction alone does not prove opposite charge; a neutral object is attracted too.
- Recognise the standard symbol for each component in a circuit diagram and draw it yourself: diode, switch, voltmeter, ammeter, variable and fixed resistor, light source, battery and single cell. In a diagram the ammeter sits in series and the voltmeter in parallel.
- Say what distinguishes alternating current from direct current: whether the current keeps one direction or keeps reversing. A cell or battery supplies direct current, never alternating.

P2 · Magnetism and electromagnetism

- Name the two poles of a magnet as north and south, and say which pairs of poles attract and which repel. Two north poles repel each other; a north and a south attract.
- Sketch the field lines round a bar magnet, with arrows leaving the north pole and entering the south. Field lines run north to south outside the magnet and never cross.
- Say what distinguishes a magnetically soft material from a magnetically hard one: how easily each is magnetised and how well it keeps its magnetism afterwards. Soft iron loses its magnetism when the field is removed; steel keeps it.
- State that a current flowing in a wire produces a magnetic field around it, and that a compass needle nearby turns as a result. The field exists only while current flows; stop the current and it vanishes.
- Sketch the field around a long straight wire (concentric circles) and around a coil or solenoid (the pattern of a bar magnet), and give the direction of each from the direction of the current. Reverse the current and every field line reverses; use the right-hand grip.
- Recognise that when a current flows along a wire lying in a magnetic field, the wire can be pushed by a force. No force arises when the current runs parallel to the field lines.
- Work out which way the force on the wire acts from the directions of the current and the field, using the left-hand rule. Reversing the current or the field reverses the force; reversing both does not.
- Say what decides how strong the force on the wire is, and how it changes when the current, the field strength or the length of wire in the field is increased.
- Explain why a voltage appears across a wire whenever it slices through field lines, and also whenever the magnetic field around it changes. No voltage is induced while the field is steady and the wire stays still.
- List the things that decide how big the induced voltage is, and say how changing each one affects it. The rate of cutting field lines matters, not the field strength alone.
- Say what decides the direction of the induced voltage, and show that reversing the wire's motion or the field reverses it.
- Tell a step-up transformer from a step-down one, and say what each does to the voltage. Step-up refers to the voltage, not to the current or the power.
- Relate the voltage on each coil to its number of turns: secondary voltage over primary voltage equals secondary turns over primary turns, and rearrange to find whichever is missing. Keep secondary over primary on both sides; a flipped ratio inverts the answer.

P3 · Mechanics

- Explain what separates a scalar from a vector, a vector having a direction as well as a size, and say which kind a given quantity is.
- Distinguish distance from displacement, and speed from velocity: in each pair the first is a scalar, the second is a vector with a stated direction. A body back at its start has zero displacement but non-zero distance.
- Use speed = distance divided by time, and velocity = change in displacement divided by time, in calculations, finding whichever quantity the question leaves out. Average speed is total distance over total time, not the mean of speeds.
- Recognise the kinds of force a question may name and what each one is: weight, the normal contact force, drag such as air resistance, friction, magnetic and electrostatic forces, thrust, upthrust, lift and tension. The normal contact force acts at right angles to the surface, not vertically.
- For each kind of force, weight, drag, friction and the rest, say what decides how big it is and which way it acts.

- Read information off a force-extension graph, such as the extension at a given force and where the line stops being straight. Check which axis carries force; the gradient's meaning flips with the axes.
- Tell elastic extension, which vanishes when the load is removed, from inelastic extension, which stays, and say what the elastic limit marks. The elastic limit and the limit of proportionality are not the same point.
- Apply Hooke's law, $F = kx$, linking force, spring constant and extension, and say what the limit of proportionality means for where the law stops holding. x is the extension beyond the natural length, not the total length.
- State Newton's first law and explain it: an object keeps still, or keeps moving steadily along a straight line, until a resultant force from outside acts on it. Constant velocity means zero resultant force, even when several forces act.
- Understand mass as the measure of how much a body resists having its motion changed. Inertia is a property of the mass, not a force acting on it.
- Explain how mass differs from weight, weight being the force gravity exerts on a mass, so it changes where gravity changes while mass does not. Weight is a force in newtons; kilograms measure mass, not weight.
- Use the gravitational field strength g, taken as 10 N/kg at the surface of the Earth, in calculations. Take g as 10 N/kg, not 9.8, unless the question says otherwise.
- Apply the link between weight, mass and gravitational field strength, $W = mg$, to find any one of the three from the other two. A mass given in grams must become kilograms before multiplying by g.
- Find an object's momentum by multiplying its mass by its velocity, $p = mv$, and rearrange the formula when a question gives you the other two quantities. Momentum has direction: give each velocity a sign and keep it.
- For motion along one straight line, set the total momentum before two bodies interact equal to the total afterwards, and solve for the unknown mass or velocity. Opposite directions take opposite signs; a rebound is a negative velocity.
- Calculate a force as the change in momentum it produces divided by the time over which it acts, and rearrange to find the change or the time. The change in momentum goes on top, not the final momentum.
- Work out the work done as the force multiplied by how far the object moves along the line of that force. Only the distance along the force's line counts, not the whole path.
- Recognise that doing work on something moves energy into it, so the work done equals the energy transferred.
- Find gravitational potential energy as mgh, taking h as the difference in height between where the object starts and where it ends. h is the height change, not the height above the ground.

P4 · Thermal physics

- Explain what makes a material a good thermal conductor or a good insulator, and name examples of each. A material that feels cold is a conductor, not a colder object.
- Say which factors set how fast heat conducts through something, the material, its thickness, its area and the temperature difference across it, and predict the effect of changing one of them. Doubling thickness halves the rate; doubling area doubles it.
- Explain why heating a liquid or gas makes it expand and so lowers its density, and use this in questions. The particles spread out; they do not get bigger.
- Explain how a warmer, less dense region of a fluid rises while cooler, denser fluid sinks to take its place, setting up a convection current. Heat does not rise; the less dense fluid does.
- Recognise that thermal radiation is a form of electromagnetic wave, sitting in the infrared part of the spectrum. Every object above absolute zero radiates, not just hot ones.
- Describe how objects absorb and emit thermal radiation, and use the balance between the two to say whether something heats up or cools down. An object absorbs and emits at the same time; the net decides.
- State what sets how fast a surface absorbs and emits thermal radiation, its colour, its finish, its area and its temperature, and predict which of two objects warms or cools faster. A dull dark surface absorbs fastest; a shiny one reflects most.
- Explain how an object's temperature rises when energy is transferred into it and falls when energy leaves it. A hotter object does not always hold more thermal energy.
- Use specific heat capacity as the energy supplied divided by the mass and by the temperature change, and rearrange it to find whichever quantity is missing. A temperature change is the same in kelvin and Celsius; never add 273.

P5 · Matter

- Describe how solids, liquids and gases differ in shape, volume, whether they flow and how easily they compress. Liquids and solids barely compress; only gases do.
- Picture each state as particles with a particular arrangement, spacing and motion, and use that picture to answer questions. Liquid particles touch each other; they are not widely spaced like a gas.

- Account for the behaviour of each state, why a solid keeps its shape, a liquid flows and a gas spreads out and can be squashed, using how its particles move, how far apart they sit and how strongly they attract one another. A gas compresses because of the gaps, not because its particles shrink.
- Explain gas pressure as the force per unit area from particles colliding with the container walls, and temperature as a measure of the particles' average kinetic energy. Pressure comes from collisions with the container, not collisions between particles.
- With the temperature held fixed, use the rule that pressure multiplied by volume stays the same: halve the volume and the pressure doubles. A graph of P against V curves; P against 1/V is straight.
- Explain what a substance's melting point and its boiling point are: the fixed temperatures at which it changes state, with the reading holding steady while the change happens. Temperature does not rise while a substance melts or boils
- Define the latent heat of fusion and the latent heat of vaporisation: the energy that melts or boils a substance with no change in its temperature. Fusion here means melting, not burning or nuclear fusion
- Calculate with energy = mass times specific latent heat, rearranging it to find whichever of the three quantities is missing. Do not multiply by a temperature change; that is specific heat capacity
- Use density = mass divided by volume, and rearrange it to find the mass or the volume when the density is given. A cubic metre is a million cubic centimetres, not a hundred
- Describe how a density is measured in practice: weigh the sample, then find its volume by measuring a regular solid's dimensions, by displacement for an irregular solid, or with a measuring cylinder for a liquid. Take the rise in water level, not the final reading
- Rank solids, liquids and gases by density and explain the order through how closely their particles are packed. Ice floats: a solid can be less dense than its own liquid
- Use pressure = force divided by area, in pascals when the force is in newtons and the area in square metres, and rearrange it for force or area. Convert cm^2 to m^2 by dividing by 10 000, not 100
- Use pressure = depth times density times g for the pressure a liquid exerts at a given depth below its surface, and rearrange it for depth or density. This is the liquid's contribution only; add atmospheric pressure for the total

P6 · Waves

- Explain that a wave carries energy from place to place while the particles of the medium only oscillate about fixed positions and are not carried along with it. The medium is not transported; a floating cork only bobs
- Tell a transverse wave from a longitudinal one by whether the oscillation is across the direction of travel or along it. Sound is longitudinal; light and every electromagnetic wave are transverse
- Name the peaks and troughs of a transverse wave and the compressions and rarefactions of a longitudinal one, and point to each on a diagram. One wavelength is compression to compression, not compression to rarefaction
- Describe what happens when a wave meets a surface and is turned back, and show the reflected rays or wavefronts on a diagram. Wavefronts keep the same spacing after reflection
- Explain why a wave changes direction when it passes into a medium where it travels at a different speed, and sketch the bent ray or the turned wavefronts. Along the normal there is no bending, though the speed still changes
- State which of a wave's speed, wavelength, frequency and direction change on reflection and which on refraction, and which stay fixed in each case. Frequency never changes at a boundary; wavelength moves with the speed
- Construct and read a ray diagram for a plane mirror, using it to locate the virtual image and to read off its position, size and orientation. The image is laterally inverted, not upside down, and virtual
- Apply the rule that a ray leaves a reflecting surface at the same angle to the normal as it arrived, and use it to find missing angles in a diagram. Measure both angles from the normal, not from the mirror surface
- Draw and read a ray diagram for light crossing a flat boundary between two media, bending towards the normal on entering the optically denser one and away on leaving it. Towards the normal when slowing down, away when speeding up
- Explain how a vibrating object makes a sound: it pushes and pulls on the medium around it, sending out a train of compressions and rarefactions.
- Explain why sound cannot cross a vacuum: it travels only by passing vibrations from particle to particle, so there has to be matter for it to move through. Light needs no medium; sound does
- Connect a bigger amplitude to a louder sound and a higher frequency to a higher pitch, in words rather than through numbers. Amplitude sets loudness only; a taller trace is not a higher note
- Describe sound as a longitudinal wave, in which the particles of the medium move back and forth along the line the sound travels rather than across it.
- Know what an electromagnetic wave is: a transverse wave, and one that crosses a vacuum at the speed of light. Unlike sound, they need no medium and are not longitudinal

- Name the regions that make up the electromagnetic spectrum, beginning with radio waves. Order by wavelength runs opposite to order by frequency

P7 · Radioactivity

- Describe any atom as a set of protons, neutrons and electrons, and count how many of each a particular atom contains. Neutrons are the mass number less the atomic number, not the mass number
- Know the nuclear model, a tiny dense positive nucleus with the electrons well outside it and empty space between, and apply it to explain how atoms behave. Nearly all the mass sits in the nucleus, nearly all the volume outside it
- Give the charge and the mass of a proton, a neutron and an electron relative to one another. A neutron carries no charge yet has about the same mass as a proton
- Explain that radioactive emission comes from the nucleus, not the electrons, and that it happens because that nucleus is unstable. Radioactivity is a nuclear change, not a chemical one
- Explain that decay is random: nobody can say which nucleus will go next or when, only how likely a decay is over a given time. Random per nucleus, yet a large sample decays at a predictable rate
- Describe what alpha, beta and gamma radiation each consist of, and how the three differ from each other in nature, charge and mass. Beta particles are electrons, but they come from the nucleus, not the shells
- Rank alpha, beta and gamma by how far each gets through matter, from alpha, stopped by paper or skin, to gamma, which needs thick lead or concrete. Penetration runs opposite to ionisation: gamma travels furthest and ionises least
- Rank alpha, beta and gamma by how strongly each ionises the matter it passes through, alpha most and gamma least. Alpha's heavy double charge makes it the strongest ioniser despite its short range
- Describe in words, not numbers, what an electric or magnetic field does to each radiation: alpha and beta bend opposite ways, beta far more than alpha, gamma not at all, and say why their charge and mass make it so. Alpha bends less than beta despite double charge: its mass is far greater
- Read a decay curve, activity or undecayed nuclei against time, and read off where the graph shows the daughter product building up as the parent falls away. The product curve rises as the parent falls, and their sum stays constant
- Define half-life as the time for half the nuclei in a sample to decay, or equally for the activity to fall by half. Two half-lives leave a quarter, not none
- Carry out half-life calculations: from three of the starting amount, the amount left, the time elapsed and the half-life, find the fourth by counting half-lives. Three half-lives cut the amount to an eighth, not a third

Chemistry

C1 · Atomic structure

- Picture an atom as a tiny nucleus of protons and neutrons at its centre, with the electrons around it arranged in shells, also called energy levels. The nucleus is tiny; most of the atom is empty space.
- Give the relative mass and charge of a proton (1, +1), a neutron (1, 0) and an electron (negligible, -1), and use them to explain why almost all of an atom's mass is in its nucleus. A neutron has the same mass as a proton; only the charge differs.
- Define atomic number (the number of protons) and mass number (protons plus neutrons), and read both from an element's standard symbol. In the symbol the mass number is on top, the atomic number below.
- Work out how many protons, neutrons and electrons a given atom or ion contains from its atomic number, mass number and charge. Neutrons are the mass number minus the atomic number, never the mass number alone.
- From its atomic number, write the electron arrangement of any element from hydrogen to calcium, filling shells 2, 8, 8 in turn and giving the answer as a comma-separated list such as 2,8,8,1 for potassium. Electrons equal the atomic number for a neutral atom, not the mass number.
- Define isotopes: atoms of one element that share a proton count but differ in their number of neutrons, and so in their mass number. Isotopes share an atomic number; it is the mass number that differs.
- Use isotope data in whatever form a question gives it, including a mass spectrum, whose peaks show the mass of each isotope and how much of it there is. Peak height gives abundance; peak position gives the isotope's mass.
- Understand relative atomic mass (Ar) as the mean mass of an element's atoms, weighted by isotope abundance, on a scale where one carbon-12 atom counts as exactly 12. Ar is rarely a whole number, because it averages across isotopes.
- Calculate an Ar from isotope masses and abundances: multiply each mass by its abundance, add the results, then divide by the total abundance. Weight by abundance; do not take a plain average of the isotope masses.

C2 · The Periodic Table

- Know that a Period runs across the table as a row and a Group runs down it as a column. Row is Period, column is Group: the two get swapped.
- Know that the elements sit in order of rising atomic number. Ordering is by atomic number; a few elements are out of mass order.
- Say where the metals and non-metals sit: Group 1 holds the alkali metals, Group 2 the alkaline earth metals, Group 16 the common non-metals, Group 17 the halogens, Group 18 the noble gases, and the transition metals fill the central block. Group 16 uses the 1 to 18 numbering: oxygen and sulfur, not Group 6.
- Work out an atom's electron arrangement from its Group and Period, and place an atom in the table from its arrangement. Period number counts the shells; Group number counts outer electrons, not shells.
- Explain that elements sharing a Group react alike, and that reactivity rises down a Group of metals but falls down a Group of non-metals. The trend flips between metals and non-metals; halogens get less reactive going down.

C3 · Chemical reactions and equations

- Explain that a reaction makes new substances by reshuffling atoms and their electrons, while every nucleus survives untouched. Atoms are conserved in a reaction; do not confuse this with nuclear change.
- Give from memory the formula of a common ionic or covalent compound. Balance the charges in an ionic formula: magnesium chloride is MgCl2, not MgCl.
- Put the right state symbol after each formula in an equation: (s) solid, (l) liquid, (g) gas, (aq) dissolved in water. (aq) means dissolved in water; liquid water itself is (l).
- Build the equation for a reaction and balance it so each element has equal atoms on both sides. Balance by changing the numbers in front, never the subscripts inside a formula.
- Construct and balance ionic equations and half-equations as well, so that charge balances on both sides along with the atoms. Spectator ions drop out of an ionic equation; electrons appear in a half-equation.
- Recognise that many reactions can run backwards as well as forwards, so they stop short of using up the reactants. Reversible means both directions run at once, not that it later undoes itself.
- Know that in such a reaction only part of the starting material becomes product: in a closed system the mixture settles at equilibrium with reactants and products both present. At equilibrium both directions still run; the amounts stay steady, nothing has stopped.

C4 · Quantitative chemistry

- Add up the relative atomic masses, Ar, of every atom in a formula to find Mr, the relative formula mass. A subscript after a bracket multiplies every atom inside the bracket.
- Know that one mole of any substance holds a fixed count of particles, and that this count is Avogadro's number. Multiply moles by Avogadro's number for particles; divide particles by it for moles.
- Know that the mass of one mole is Ar or Mr written in grams, and convert a mass in grams into moles and moles back into grams. Moles equal mass divided by Mr, not Mr divided by mass.
- Carry out the same conversions when the mass is quoted in kilograms or tonnes, and know that the amount of any substance means its number of moles. A tonne is a million grams, a kilogram a thousand: convert before dividing.
- Work out the percentage of a compound's mass that each element contributes, from its formula and the Ar values you are given. Count every atom of the element in the formula before dividing by Mr.
- Know that an empirical formula shows the elements of a compound in their smallest whole-number ratio. Reduce the ratio fully: C2H4 is not empirical, CH2 is.
- Derive the empirical formula from whatever data you are given, for instance the percentage of the mass that each element contributes. Divide each mass or percentage by that element's Ar before comparing the ratios.
- From a balanced equation, use the mole ratio to find the mass of one substance from the known mass of another, whether reactant or product. Convert to moles, apply the ratio, convert back; never scale masses directly.
- Where the reactants are not supplied in the ratio the equation needs, identify which one runs out first and base the product mass on that one. Compare moles divided by coefficient, not raw mass, to find which runs out.
- Work backwards from measured reacting masses, or from gas volumes, to a mole ratio, and from that write the balanced equation. Masses must become moles first; only gas volumes give the ratio directly.
- Know that at a fixed temperature and pressure an ideal gas takes up the same volume for every mole, and that at room temperature and pressure this is 24 dm3. Use that figure to convert between the volume of a gas and its number of moles. 24 dm3 applies to gases only, and only at rtp.
- Know that concentration is quoted in moles per dm3 or in grams per dm3, and calculate it from the amount of solute, as moles or as mass, and the volume of the solution. Volumes given in cm3 must be divided by 1000 before use.
- Do titration calculations: combine the concentrations of the solutions, either given or worked out from data, with the mole ratio from the balanced equation. Apply the equation's mole ratio; the acid and base moles are often unequal.
- Find the percentage yield: use the balanced equation to predict the mass of product, then divide the mass actually obtained by that prediction and multiply by 100. Actual divided by predicted, never the reverse: yields cannot exceed 100 per cent.

C5 · Redox

- Know the simplest definition: a substance is oxidised when it gains oxygen and reduced when it loses oxygen. The substance losing its oxygen is the one being reduced.
- Treat oxidation and reduction as electron transfer: a species is oxidised when it loses electrons and reduced when it gains them, and apply this to reactions. Gains oxygen but loses electrons: both mean oxidised, do not mix the two.
- Assign an oxidation state to each atom in a simple inorganic compound, and use those states in your reasoning. States sum to zero in a compound, to the charge in an ion.
- Look at an equation and decide whether it shows oxidation alone, reduction alone, both together as redox, or neither. Neutralisation and precipitation move no electrons: they are neither oxidation nor reduction.
- Know that disproportionation is one species being oxidised and reduced in the same reaction, and pick out the reactions, or the species, where it happens. The same element must go up and down in oxidation state.
- Say what an oxidising agent and a reducing agent each do to the other reactant, and name which is which in a given equation. The oxidising agent is itself reduced: it takes the electrons.

C6 · Bonding and structure

- Define what an element, a compound and a mixture each are, and explain how the three differ from one another. A compound has fixed proportions; a mixture can have any composition.
- Know that atoms tend to react so that each ends up with the full outer shell of a Group 18 element, and that which kind of bond forms depends on which atoms are involved. Hydrogen is full at two electrons, not eight.
- Know that a metal atom hands electrons to a non-metal atom, leaving a positive ion and a negative ion, and that the pull between the opposite charges is what holds an ionic compound together. Metals lose electrons and become positive, not negative.

- Use an atom's electron configuration to predict the charge on its most stable ion, for an element in Group 1, 2, 16 or 17 and for aluminium.
- Know that a covalent bond is two atoms, nearly always both non-metals, holding a shared pair of electrons between them, and that more than one pair can be shared. Sharing is not transfer: no ions form in a covalent bond.
- Know that a covalent substance is made either of small separate molecules, such as water, ammonia or methane, or of one giant structure, such as diamond, graphite or silicon dioxide. The bonds inside a molecule stay strong even when the substance melts easily.
- Picture a solid metal as positive ions packed into a lattice, with the outer electrons free to move through the whole structure rather than tied to any one atom. The ions are positive because each atom has released its outer electrons.
- Know the physical properties metals typically share, above all melting point and conductivity, and explain each from the picture of ions in a sea of free electrons. Conduction is the free electrons moving; the ions stay put.
- Know that molecules attract one another through forces acting between them, and that it is these attractions that must be broken for a substance to melt or boil. Boiling water breaks the forces between molecules, not the O-H bonds.
- From a substance's structure and the type of bonding in it, predict and explain its physical properties, above all its melting point and whether it conducts electricity. Ionic solids conduct only when molten or dissolved, never as solids.

C7 · Groups 1, 17 and 18

- Know the physical properties and the chemical behaviour of three families: the alkali metals in Group 1, the halogens in Group 17 and the noble gases in Group 18. Group 1 metals are soft and low in density, unlike typical metals.
- Describe how the alkali metals change in reactivity and in their physical properties going down the group, and use that pattern to predict how a member you have not been told about behaves. Reactivity rises down Group 1, the opposite way to the halogens.
- Know the order in which lithium, sodium and potassium sit going down Group 1, so that the trend is applied the right way round. Lithium is at the top of the group, not partway down.
- Know which elements make up the halogens, Group 17, and treat them as one family whose members follow shared trends. Group 17 is the family older numbering called Group 7.
- State how reactivity and the physical properties shift from one halogen to the next down Group 17, and extend the pattern to predict the behaviour of any member. Down Group 17 reactivity falls while melting and boiling points rise.
- Know the order in which the halogens sit within Group 17, so that a trend can be read off in the right direction. The order downward is fluorine, chlorine, bromine, iodine.

C8 · Separation techniques

- Know that getting an element back out of a compound takes a chemical reaction, and that no physical method will do it. Filtering or distilling cannot split a compound into its elements.
- Know that a mixture is taken apart by physical methods, and that no chemical reaction is needed to do it. Separating a mixture changes no substance; each part keeps its identity.
- Cover the four cases: two liquids that mix, two that will not, a solid dissolved in a liquid, and a solid that stays undissolved, and know a physical method suited to each. Immiscible liquids settle into layers; miscible ones blend into a single liquid.
- Say which mixtures call for simple distillation, which for fractional distillation and which for paper chromatography. Close boiling points need fractional distillation, not simple.
- Calculate and interpret Rf values from a chromatogram, and know when a separating funnel, a centrifuge, dissolving or filtration is the right way to separate a mixture. Rf is spot distance over solvent front distance, and never exceeds one.
- Judge from a chromatogram whether a sample is pure: a single spot points to one substance, more than one spot to a mixture. Spot count tells you purity, matching Rf values tell you identity.

C9 · Acids and bases

- Define an acid in either of two ways: a substance that produces H+(aq) ions in water, or one that hands H+ to something else. Containing hydrogen is not enough: methane donates no H+.
- Describe how an acid reacts with a metal, a carbonate, a metal hydroxide and a metal oxide: each gives a salt, together with hydrogen, with water and carbon dioxide, or with water alone. Hydrogen comes only from the metal reaction, carbon dioxide only from carbonates.
- Define a base in either of two ways: a substance that produces OH-(aq) ions in water, or one that takes H+ from something else. A base need not contain OH: ammonia qualifies by accepting H+.

- Explain what strong, weak, dilute and concentrated mean and keep the pairs apart: strong or weak describes how fully a substance splits into ions in water, dilute or concentrated describes how much of it is dissolved in a given volume. Strong is not concentrated: a strong acid can be dilute.
- Know that some metal oxides and metal hydroxides react with water to give an alkaline solution. Non-metal oxides such as CO2 are acidic, not basic.
- Know that an acid and a base can react to neutralise each other, and that the reaction usually releases heat. Exothermic means the mixture gets warmer, so the temperature rises.

C10 · Rates of reaction

- Say whether a reaction gets faster or slower when you change the concentration, the temperature or the particle size, add a catalyst, or, for a gas, change the pressure. Smaller pieces mean more surface area, so the rate goes up, not down.
- Know that a rate can be followed by tracking how quickly a reactant is used up, how quickly a product forms, or how a physical property changes over time, and say which of these measurements suits a given reaction. Measuring mass loss only works when a gas escapes from the flask.
- Read a graph of amount against time for a reaction: the gradient at any point is the rate, and a flat line means the reaction has finished. Compare rates by gradient, not by how much product forms in the end.
- Explain any change in rate through collisions: particles react only when they collide with enough energy, so the rate rises when collisions happen more often or when a greater share of them have the energy needed to react. Heating makes collisions more energetic as well as more frequent; say both.
- Know that colliding particles react only if they carry at least a minimum energy, the activation energy (Ea), and pick out Ea on an energy level diagram as the rise from the reactants to the peak. Ea runs from the reactants up to the peak, not down to the products.
- Know that a catalyst is not consumed: the amount present at the start is still there when the reaction finishes. Never count the catalyst as a reactant when balancing the equation.
- Know that a catalyst is chemically the same substance after the reaction as before it. Chemically the same does not mean physically the same: appearance may change.
- Know that a catalyst works by opening a different pathway, a new mechanism, with a smaller activation energy than the uncatalysed route, and show this on an energy level diagram as a lower peak between the same reactant and product levels. It lowers the barrier, not the energy difference between reactants and products.

C11 · Energetics

- Tell exothermic from endothermic by the sign of the enthalpy change. Exothermic reactions give energy out and have a negative enthalpy change; endothermic reactions take energy in and have a positive one. Negative enthalpy change means exothermic: energy has left the reacting substances.
- Know that a reversible reaction which gives energy out in the forward direction takes energy in when it runs backwards, and the other way round. Reverse the equation and the sign of the enthalpy change flips too.
- Read an energy level diagram: pick out the energy levels of reactants and products, the enthalpy change between them, the activation energy, and whether energy is given out or taken in. The enthalpy change is products minus reactants, not the height of the peak.
- Work out the energy transferred in a calorimetry experiment from the mass being heated, its specific heat capacity and the temperature rise or fall. Use the mass of the water being heated, not the mass of the reactant.
- Know that breaking a bond takes energy in while making one gives energy out, and use a table of bond energies to work out the overall energy change of a reaction. Total bonds broken minus total bonds made: count every bond in every molecule.

C12 · Electrolysis

- Know the vocabulary: an electrode is the conductor dipped into the liquid where current enters or leaves it, the cathode is the negative electrode, the anode is the positive electrode, and the electrolyte is the molten substance or solution that conducts between them. Cations go to the cathode and anions to the anode: match the initials.
- Explain why electrolysis runs on direct current: the electrodes must keep a fixed sign so that each ion is always pulled the same way, and alternating current would swap them every cycle. The reason is fixed polarity, not voltage, power or safety.
- Know that at the cathode the positive ions, the cations, gain electrons, which is reduction, and become atoms or molecules; at the anode the negative ions, the anions, lose electrons, which is oxidation, and become atoms or molecules too. Gaining electrons is reduction, not oxidation: remember OIL RIG.
- Predict what is produced at each electrode when an aqueous solution, a salt solution included, is electrolysed. A solution is not the molten salt: water's own ions take part too.

- Work out which species is discharged when more than one kind of ion or molecule is pulled towards the same electrode. Hydrogen forms at the cathode unless the metal is less reactive than hydrogen.
- Write a half-equation for what happens at the cathode and another for what happens at the anode, with the electrons on the correct side of each. Electrons go on the left for reduction and on the right for oxidation.
- Explain how electrolysis puts a thin metal coat on an object: the object is made the cathode, the coating metal is the anode, and the electrolyte contains ions of that metal. The object being plated is the cathode, so it must be negative.

C13 · Organic chemistry

- Know that most hydrocarbons come from crude oil, and that fractional distillation splits the oil into fractions; you will not be asked the names or uses of individual fractions. Distillation separates by boiling point; no bonds break and no new substance forms.
- Know that the alkanes form a homologous series in which a molecule with n carbon atoms carries 2n + 2 hydrogen atoms, the general formula CnH2n+2. Saturated means every carbon to carbon bond is single.
- Name any unbranched alkane with one to six carbon atoms, and go the other way, from the name to the molecule. Butane has four carbons, not two: the first four names are irregular.
- Know that the alkenes form a homologous series whose members each hold one carbon to carbon double bond, so a molecule with n carbon atoms carries 2n hydrogen atoms, the general formula CnH2n. One letter separates alkene from alkane: read the name carefully.
- Name any unbranched alkene with two to six carbon atoms, saying where the double bond sits, as in but-1-ene and but-2-ene, and go from the name back to the molecule. There is no methene: the smallest alkene has two carbons.
- Know what addition polymerisation is: many small alkene molecules join end to end to give a polyalkene. Alkanes have no double bond, so they cannot be addition monomers
- Know that molecules carrying a C=C double bond, alkenes above all, can add to one another to build one long saturated chain, and that this product is called a polymer. The chain is saturated: every C=C opens when the monomers join
- Treat the alcohols as one homologous series: every member fits CnH2n+1OH and each differs from the next by a single CH2 group. The H in OH counts: ethanol has six hydrogens, not five
- Name any straight-chain alcohol with one to six carbons and write its structure from its name, including the number that says where the OH group sits on the chain. Number the chain from the end that gives the OH the smaller number
- Treat the carboxylic acids as one homologous series: every member fits CnH2n+1COOH and successive members differ by one CH2 group. Ethanoic acid has two carbons in total, so n is 1
- Give the name of any straight-chain carboxylic acid with one to six carbons, and write down the structure that a given name describes. The COOH carbon is part of the chain: HCOOH is methanoic acid

C14 · Metals and reactivity

- Connect how reactive a metal is to how readily its atoms lose electrons to become positive ions, and to how difficult the metal is to extract from its ore. More reactive means harder to extract, not easier
- Work out a reactivity order from the results of displacement reactions, and predict from a known order whether a given displacement will happen. No reaction is evidence too: the metal added sits below the other
- Explain why a metal is chosen for a particular job in terms of its physical properties and its chemical properties. Name the property behind the use: conducts, resists corrosion, is light
- Know the use-and-property pairings for aluminium, iron, copper, silver, gold and titanium, and know that metals are mixed into alloys to give a material the particular properties a job needs. An alloy is a mixture, not a compound
- Know that most ores hold the metal as its oxide, and that extracting a metal from any ore always involves reducing it, whatever the method. Reduction here means the oxide loses oxygen, or the metal ion gains electrons
- Know that a transition metal can form more than one stable ion, each in a different oxidation state, iron as Fe2+ or Fe3+ for example. Do not assume a metal makes just one ion: read the roman numeral
- Know that the compounds a transition metal forms are usually coloured, so colour in a solid or a solution points to a transition metal being present. It is the compounds that are coloured, not the metal itself
- Know that a transition metal is often used as a catalyst to speed up a reaction. A catalyst is not used up, so it is not a reactant

C15 · Particle model

- Describe how closely packed and how ordered the particles are in a solid, a liquid and a gas, and how they move in each: vibrating about fixed positions, sliding past one another, or travelling freely. Liquid particles still touch: their spacing is close to a solid's

- Explain what happens to the spacing, arrangement and motion of the particles when a substance freezes, melts, boils or evaporates, and condenses. The particles themselves never expand or shrink; only spacing and motion change
- Understand that the energy needed to melt or boil a substance depends on its bonding and structure: the stronger the forces holding its particles together, intermolecular forces included, the more energy the change takes. Temperature stays constant during a change of state while energy is transferred

C16 · Chemical tests

- Test for hydrogen by holding a lit splint at the mouth of the tube: the gas burns with a squeaky pop. Lit splint for hydrogen, glowing splint for oxygen; do not swap them
- Test for oxygen with a splint that is glowing but not alight: in oxygen it bursts back into flame. The splint goes in glowing, not burning; relighting is the positive result
- Test for a carbonate by adding dilute acid: it fizzes, giving off carbon dioxide, which limewater will confirm. Carbonate plus acid gives carbon dioxide, not hydrogen; metal plus acid gives hydrogen
- Test for a halide by adding silver nitrate solution after acidifying the sample with dilute nitric acid, and read the halide from the colour of the precipitate: white for chloride, cream for bromide, yellow for iodide. Acidify with nitric acid, never hydrochloric: chloride ions would give a false positive
- Recognise that adding sodium hydroxide solution to a solution of Al3+, Ca2+ or Mg2+ ions gives a white precipitate. A white precipitate does not by itself say which of the three.
- Recognise that copper(II) ions give a blue precipitate when sodium hydroxide solution is added. The blue solid is the sign; copper solutions are blue before testing.
- Recognise that iron(II) ions give a green precipitate with sodium hydroxide solution. Green here means iron(II), not copper, whose green shows in a flame.
- Match each flame colour to its metal ion: lithium burns crimson red, sodium yellow-orange, potassium lilac, calcium red-orange and copper green. Lithium's crimson and calcium's red-orange are the pair most often swapped.
- Test for water by dropping it onto anhydrous copper(II) sulfate and watching the powder go from white to blue. The change shows water is present, not that the water is pure.

C17 · The atmosphere

- Recall the proportions of the gases in dry air, use them in a calculation, and explain that fractional distillation separates those gases. The remaining one percent is mostly argon, not carbon dioxide.
- State where greenhouse gases such as carbon dioxide and methane come from, and describe the effects they have on the climate. Do not mix greenhouse warming up with damage to the ozone layer.
- Explain where carbon monoxide, carbon dioxide, sulfur dioxide and the nitrogen oxides come from and what harm each one does. Nitrogen oxides form from air nitrogen at engine temperatures, not from the fuel.
- Explain what chlorine is for, and what fluoride ions are for, when drinking water is treated. Chlorine kills microbes and fluoride protects teeth: two purposes, keep them apart.
- Explain that rubbing an insulator leaves it carrying a charge. Rubbing moves electrons only; protons stay put, so charge is transferred, not made.

Biology

B1 · Cells and organisation

- Describe the cell membrane of an animal or plant cell, a thin partially permeable layer round the cytoplasm, and explain its job of controlling what passes into and out of the cell.
- Describe the cell wall, which plant cells have and animal cells lack, and explain what it does for the cell. The wall gives support and shape; it does not control what enters
- Describe the chloroplast, present in plant cells but not in animal cells, and explain its role in the cell. Chloroplasts photosynthesise; respiration is the mitochondrion's job
- Describe the membrane of a bacterial cell and state its role, which is to control what enters and leaves the cell.
- Describe the wall that surrounds a bacterial cell and explain what it does for the cell. Bacteria have a wall too, and it is not made of cellulose
- Know that a bacterium keeps its main DNA as a chromosome lying free in the cytoplasm, since it has no true nucleus to hold it, and say what that DNA does for the cell. Prokaryotes do have DNA; what they lack is a nucleus
- Describe plasmid DNA, a small separate loop of DNA that a bacterium carries as well as its chromosome, and say what it does for the cell. A plasmid is extra DNA; it is not the bacterial chromosome
- Place any part of an organism in the hierarchy that runs from cells, through tissues and organs, up to organ systems, and say what each level means. A tissue is many similar cells; an organ combines several tissues

B2 · Transport across membranes

- Define diffusion, osmosis and active transport, giving osmosis as the movement of water from higher to lower water potential across a partially permeable membrane, and say which of the three needs energy from the cell. State osmosis in water potential terms, high to low; 'concentration' alone is ambiguous
- Recognise these three processes in examples, some drawn from living organisms and some from settings where nothing is alive. Active transport happens only in living cells; diffusion needs no life at all

B3 · Cell division and reproduction

- Know what the mitotic cell cycle is: the repeating sequence in which a cell grows, copies its DNA and then divides once to make two identical cells.
- Split that cycle into its two parts: interphase, when the cell grows and its DNA is replicated, and mitosis, a single division that gives two daughter cells, each a genetic match for the other and for the parent cell. Interphase is not a rest: growth and DNA copying both happen there.
- Know what the meiotic cell cycle is: a cell grows, copies its DNA and then goes through two divisions to make four cells.
- Split the meiotic cycle into interphase, when the cell grows and replicates its DNA, and meiosis, two divisions one after the other that leave four daughter cells, each holding just one copy of every chromosome. DNA is copied once, before meiosis, even though two divisions follow.
- State that asexual reproduction needs only one parent and gives offspring that are genetic copies of it, unless a mutation intervenes. The offspring are identical only when no mutation has occurred.
- State that sexual reproduction needs two parents and gives offspring that differ genetically from each other and from both parents, which is where extra variation comes from.
- Give the sex chromosomes for most mammals, humans among them: XX for a female, XY for a male. The rule is stated for most mammals, not every animal.
- Use genetic data or a genetic diagram to work out the sex of an offspring and the ratio of males to females a cross is expected to give. Only the father's gamete decides sex: the mother always gives an X.

B4 · Genetics

- Know that in a eukaryotic cell the nucleus is one place where the genetic material is kept.
- Define and use each of these terms correctly: gene, allele, dominant, recessive, heterozygous, homozygous, phenotype, genotype, chromosome and autosome. Genotype is the alleles carried; phenotype is what actually shows.
- Use and read genetic diagrams for a monohybrid cross, one that follows a single gene, and interpret the genetic data such a cross gives. Each gamete carries one allele of the gene, never both.
- Read a pedigree chart to work out genotypes and the chance of a trait appearing, and give the answer as a ratio, a count, a probability or a percentage. Two unaffected parents with an affected child means the trait is recessive.

B5 · DNA and protein synthesis

- Define the genome as all the DNA an organism carries, taken together. The genome is the complete set, not a single gene or chromosome.
- State that chromosomes are the structures that hold this DNA.
- Describe a single strand of DNA (ssDNA) as a polymer: a chain built from nucleotide units linked end to end. The repeating unit is the nucleotide, not the base on its own.
- Describe double-stranded DNA (dsDNA) as a polymer too, this time two strands wound round each other in a double helix.
- Know that making a protein means joining amino acids into a chain, and that such a chain is a polypeptide.
- Know that a working protein may be a single polypeptide or several polypeptides combined. One polypeptide is not always a whole protein; some need several.
- Know that a protein's three-dimensional shape follows from the order of its amino acids.
- Know that a mutation is a change in the order of nucleotides along the DNA. A mutation is a change in the DNA itself, not in the protein.
- Know that mutations vary in their effect: the majority leave the phenotype unchanged, a few alter it slightly, and now and then one decides it outright. Most mutations are neutral; do not assume every mutation is harmful or visible.

B6 · Genetic engineering and selection

- Describe how genetic engineering works: a gene is copied from one organism's DNA and put into the DNA of a different organism, and say what restriction enzymes and ligases each do when the DNA is recombined. Restriction enzymes cut DNA at specific sites; they do not join the pieces.
- Know that some cells of the early embryo are totipotent: any one of them could grow into an entire organism made up of many cells. Totipotent is the stronger term: a whole organism, not merely many cell types.
- Know that most of the stem cells in an embryo are pluripotent: they can differentiate into any type of cell. Most, not all, embryonic stem cells are pluripotent: a few are totipotent.
- Compare natural selection with selective breeding: say what the two have in common and where they differ. Both change a population over generations; only who chooses the parents differs.
- Explain the effect that selective breeding has on a population over time. Think about the population's gene pool, not just the individuals picked to breed.

B7 · Evolution and variation

- Know that the individuals making up a population of one species usually differ from each other genetically, and to a large degree. Variation here is between members of one species, not between different species.
- Define evolution as the alteration of a population's heritable traits across generations, brought about by natural selection, which can in time produce a new species. Populations evolve; an individual cannot change its own inherited characteristics during its life.
- Recognise that differences between individuals can be genetic, passed on from parents, and that this produces a spread of phenotypes. Phenotype is the observable trait; genotype is the alleles behind it.
- Recognise that an organism's surroundings can also cause differences between individuals, so the environment too shapes the phenotypes seen. A trait picked up from the environment is not passed to offspring.

B8 · Enzymes and digestion

- Know that enzymes are mostly proteins and that they act as catalysts in living organisms. Enzymes speed reactions up without being used up or altered by them.
- Explain in outline how an enzyme works: the substrate binds to it, is converted into product, and the enzyme is released unchanged to act again. Substrate is what the enzyme acts on; product is what it makes.
- Describe the part the active site plays and explain why an enzyme is specific: only one substrate, or one kind of substrate, fits into its active site. Say the substrate fits the active site, not the enzyme fits the substrate.
- Explain how a change in temperature, or in pH, alters how quickly an enzyme works, and why. A denatured enzyme has lost its active site shape; it has not died.
- Match each digestive enzyme to what it breaks down: amylases act on carbohydrates, proteases on proteins and lipases on fats. Each enzyme digests one food type only: amylase does not touch protein.

B9 · Human physiology

- Explain what respiration is: the process going on inside every living cell, and what it achieves for the cell. Respiration is not breathing: it happens inside cells, breathing just moves air.
- Describe aerobic respiration in cells and be able to write out its word equation. Oxygen is a reactant here; in photosynthesis it is a product.
- Describe anaerobic respiration in animal cells, the process a cell uses when it has too little oxygen, and be able to write out its word equation. Anaerobic respiration still releases energy, only less of it than aerobic.
- Know which two parts make up the central nervous system: the brain together with the spinal cord. Nerves running out to the body are peripheral, not part of the central system.
- Describe how each of the three neurone types, sensory, relay and motor, is built and what it does, and do the same for a synapse and for the reflex arc. Sensory neurones carry impulses towards the central nervous system, motor neurones away from it.
- Define homeostasis as keeping conditions inside the body steady, and explain why an animal built of many cells depends on it. Steady means held within a narrow range, not fixed at one exact value.
- Explain how negative feedback keeps homeostasis going: a shift away from the normal level triggers a response that pushes it back. Negative here means opposing the change, not harmful and not switched off.
- Explain how the level of glucose in the blood is regulated, including what insulin and glucagon each do.
- Understand that each hormone is made by a particular endocrine gland, released into the blood, and carried to the organ or tissue it acts on. Hormones travel in the blood, not along nerves, so their effects are slower.
- Describe adrenaline's main job: preparing the body for sudden action, the fight or flight response, when it meets danger or stress.
- Describe what FSH, LH, oestrogen and progesterone each do across the menstrual cycle, name the hormones used in contraception, and explain how hormonal and non-hormonal methods of contraception differ.
- Know that a communicable disease is one that can be passed from person to person, and revise what causes these diseases, how they spread, how they are treated and prevented, and how new medicines and vaccines are tested. A communicable disease can be passed on; many diseases cannot be caught.
- Know that a communicable disease is caused by a pathogen, which may be a bacterium, a virus, a fungus or a protist. A pathogen is any microbe that causes disease, not only bacteria.
- Explain how a sexually transmitted infection passes from person to person, and how HIV damages the immune system so that, untreated, it leads to AIDS. Some also spread through blood or from mother to baby, not only sexually.

B10 · Ecology

- Define individual, population, community and ecosystem, and put the four in order from the single organism up to the whole system. A community is all the living things; an ecosystem adds the non-living surroundings
- Explain how a community can be changed by abiotic factors, the non-living conditions of its habitat, and by biotic factors, the effects of the other living things in it.
- Trace carbon round the carbon cycle and explain what each of photosynthesis, respiration, combustion and decomposition contributes to keeping it moving. Only photosynthesis takes carbon dioxide out of the air; the other three return it
- Explain why the water cycle matters to living things, and what they would lose without it.
- Describe how you would use quadrats and a belt transect to find out how many of an organism live in a habitat and where they are, and interpret the data such a survey gives. Random quadrats measure abundance; a transect tracks change along a line
- Work out how many organisms of one species there are in a given area from the counts in a sample of it, scaling up from the area you sampled to the whole.

B11 · Photosynthesis and plant transport

- Write photosynthesis as carbon dioxide plus water giving glucose and oxygen, and know that it is endothermic because it takes in energy from light. Photosynthesis is endothermic: energy in from light, unlike respiration
- Explain how each of temperature, light intensity and the concentration of carbon dioxide can limit the rate of photosynthesis, and what happens to the rate as each one is raised. Warmer is faster only up to a point; enzymes then denature
- Know that a plant has transport tissues, xylem and phloem, that carry substances from one part of it to another.
- Describe how xylem and phloem are built, and link each feature of their structure to the job that tissue does in the plant. Xylem is dead and hollow; phloem is living: keep their features apart
- Explain why xylem is built from dead cells with lignin in their walls, and how that suits it to carrying water and dissolved mineral ions up from the roots to the stem and leaves. Lignin is there for strength and waterproofing, not to move the water