Course Companion

Pearson Edexcel · International GCSE · Mathematics A

Every topic handout in one volume

exercises.lol

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Numbers and the number system

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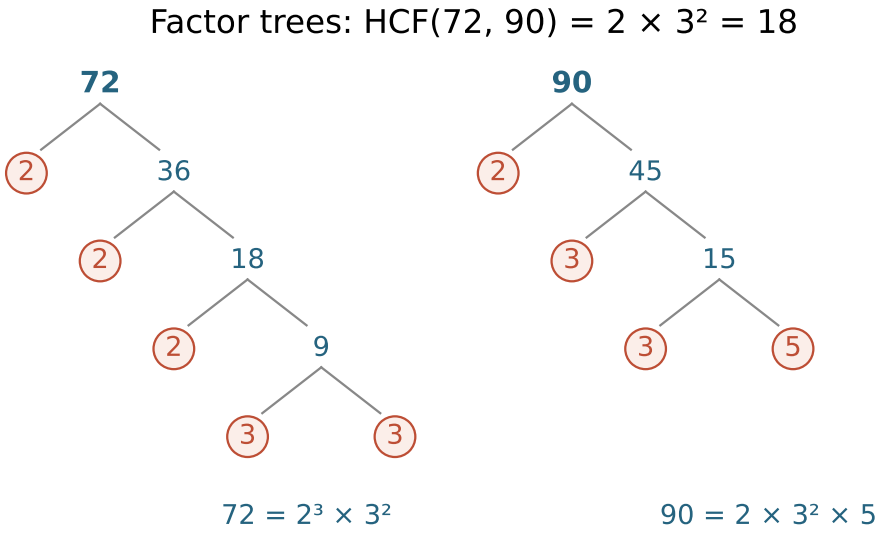
4MA1 topic 1 (specification Issue 2, November 2017) is the number heart of the qualification: Foundation rows 1.1–1.11 run from integers and the four rules through fractions, decimals, indices, sets, percentages, ratio, bounds and standard form to everyday number work; Higher adds recurring-decimal conversion, surds, algebraic sets, repeated percentage change and bound problems. On the June 2024 papers this strand supplied reverse percentage (2HR Q8), standard form (2HR Q9), the recurring-decimal proof (2HR Q18), upper-bound multiplication (2HR Q19), surds rationalisation (1HR Q17 family) and prime factors with Venn regions (1HR Q11 family).

Must-know for topic 1:

Family	Formulae
percentages	multiplier $1 + \frac{r}{100}$ (increase), $1 - \frac{r}{100}$ (decrease); reverse: original = final $\div$ multiplier
bounds	value v to 1 d.p. has LB $= v - 0.05$, UB $= v + 0.05$; maximise products by multiplying upper bounds
standard form	$a \times 10^n$ with $1 \le a < 10$; indices add on multiplication, subtract on division
ratio	share by $\dfrac{\text{parts owned}}{\text{total parts}} \times$ amount

Integers, four rules and the hierarchy of operations

Integers cover positive, negative and zero; place value names each digit's worth. Directed numbers appear in practical settings (temperature, debt, sea level); ordering puts them on the number line. The four rules with negatives: same signs add, different signs subtract, two negatives make a positive. **Brackets, then indices, then divide/multiply, then add/subtract** (BIDMAS): $3 + 4 \times 2^2 = 3 + 16 = 19$, while $(3+4)\times 2 = 14$. Odd, even, **prime numbers** (exactly two factors), **factors** and **multiples** classify whole numbers; common factors and common multiples lead to the HCF and LCM.



Factor trees: $72 = 2^3 \times 3^2$ and $90 = 2 \times 3^2 \times 5$, so HCF $= 2 \times 3^2 = 18$

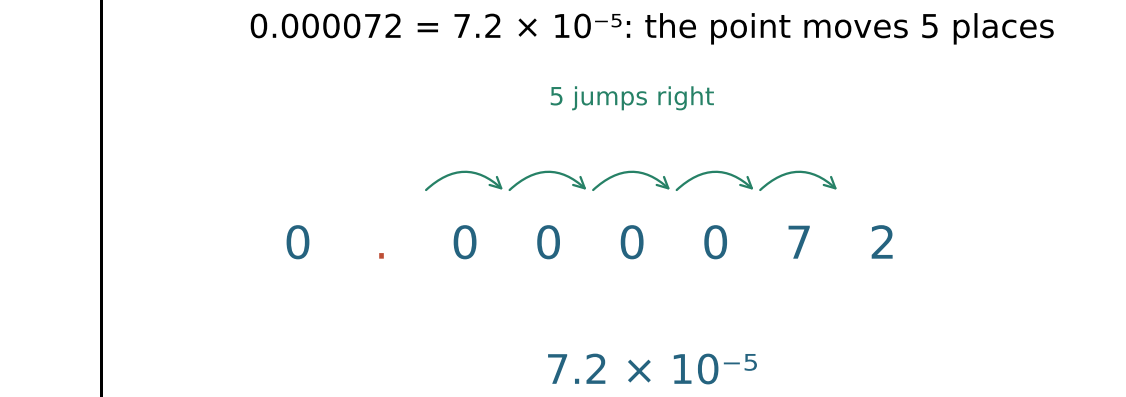
Fractions

Equivalent fractions cancel or extend: $\frac{8}{12} = \frac{2}{3}$. **Mixed numbers** and **vulgar fractions** convert by division with remainder. A **common denominator** lets fractions be ordered, compared, added and subtracted: $\frac{1}{3} + \frac{1}{4} = \frac{4}{12} + \frac{3}{12} = \frac{7}{12}$. A fraction OF a quantity multiplies: $\frac{3}{4}$ of 48 is 36; expressing one number as a fraction of another divides (7 as a fraction of 28 is $\frac{1}{4}$). Multiplying fractions multiplies numerators and denominators; dividing multiplies by the reciprocal – unit fractions as multiplicative inverses ($\frac{1}{3}$ undoes 3). Fractions convert to decimals (divide) and percentages (multiply by 100).

Recurring decimals (Higher) convert by algebra: let $x = 0.306306\ldots$; then $1000x = 306.306\ldots$; subtracting, $999x = 306$, so $x = \frac{306}{999} = \frac{34}{111}$ (June 2024 2HR Q18). A terminating decimal is a fraction with denominator a power of ten.

Decimals, indices, factors and multiples

Decimal place value runs tenths, hundredths, thousandths; ordering compares the highest-value digits first. **Square numbers** $(1, 4, 9, \ldots)$, **cube numbers** $(1, 8, 27, \ldots)$, their roots, and **index notation** with the multiplication and division laws for positive integer powers: $2^3 \times 2^4 = 2^7$ and $2^7 \div 2^3 = 2^4$. Every integer factors into primes: $360 = 2^3 \times 3^2 \times 5$; June 2024 1HR Q11 family factors large numbers into primes and reads products of regions from a Venn diagram ($19600 = 2^4 \times 5^2 \times 7^2$). The **HCF** takes the lowest power of each common prime; the **LCM** takes the highest power of every prime: for $360 = 2^3 \cdot 3^2 \cdot 5$ and $84 = 2^2 \cdot 3 \cdot 7$, HCF $= 2^2 \cdot 3 = 12$ and LCM $= 2^3 \cdot 3^2 \cdot 5 \cdot 7 = 2520$.



Moving the point 5 places right gives 7.2, so $0.000072 = 7.2 \times 10^{-5}$

Surds

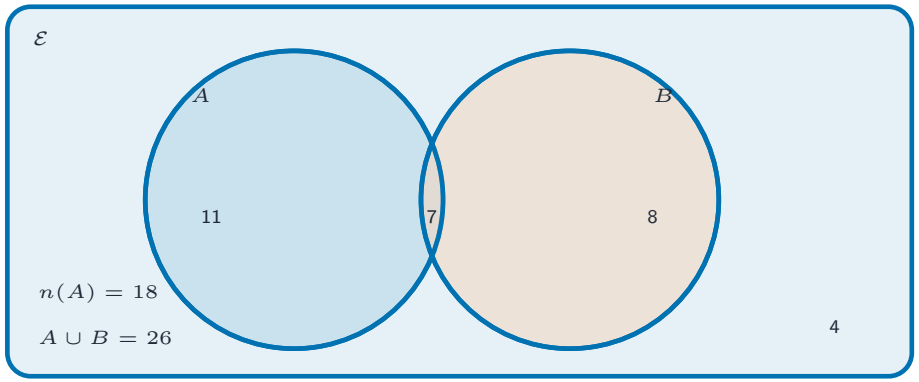
A **surd** is an exact irrational root such as $\sqrt{2}$. Simplify by extracting squares: $\sqrt{50} = \sqrt{25 \times 2} = 5\sqrt{2}$, using $\sqrt{ab} = \sqrt{a}\sqrt{b}$. Adding needs like surds: $3\sqrt{2} + 5\sqrt{2} = 8\sqrt{2}$, but $\sqrt{2} + \sqrt{3}$ does not simplify.

Rationalising the denominator removes the root by multiplying top and bottom by the conjugate – a difference of two squares clears it exactly. Worked case: $\frac{5}{3-\sqrt{2}} = \frac{5(3+\sqrt{2})}{(3-\sqrt{2})(3+\sqrt{2})} = \frac{5(3+\sqrt{2})}{9-2} = \frac{5(3+\sqrt{2})}{7}$; and $\frac{6}{\sqrt{3}} = \frac{6\sqrt{3}}{3} = 2\sqrt{3}$. June 2024 1HR Q17 family rationalises a denominator built from $2 - \sqrt{3}$ to an answer of the family $\frac{7(2+\sqrt{3})}{4}$ – since $(2-\sqrt{3})(2+\sqrt{3}) = 1$, the $(2+\sqrt{3})$ multiplier clears the surd exactly.

Sets

A **set** is a collection of elements: $A = \{2, 4, 6, 8\}$. Notation: $\cup$ (**union**, in either set), $\cap$ (**intersection**, in both), $\in$ and $\notin$ (**membership**). The **universal set** $\mathcal{E}$ contains everything under discussion; the **empty set** $\emptyset$ has no elements; the **complement** A' holds everything in $\mathcal{E}$ outside A. **Venn diagrams** draw the regions – at Higher with algebraic sets, **subsets** ($B \subset A$: every element of B lies in A), the element count $n(A)$, and practical uses (polls, prime-factor regions). June 2024 1HR Q11 family places the

prime factors of two numbers in a two-set Venn and reads products such as AB, A^2 and B^2 from combined regions – the HCF is the overlap's product, the LCM everything's product.

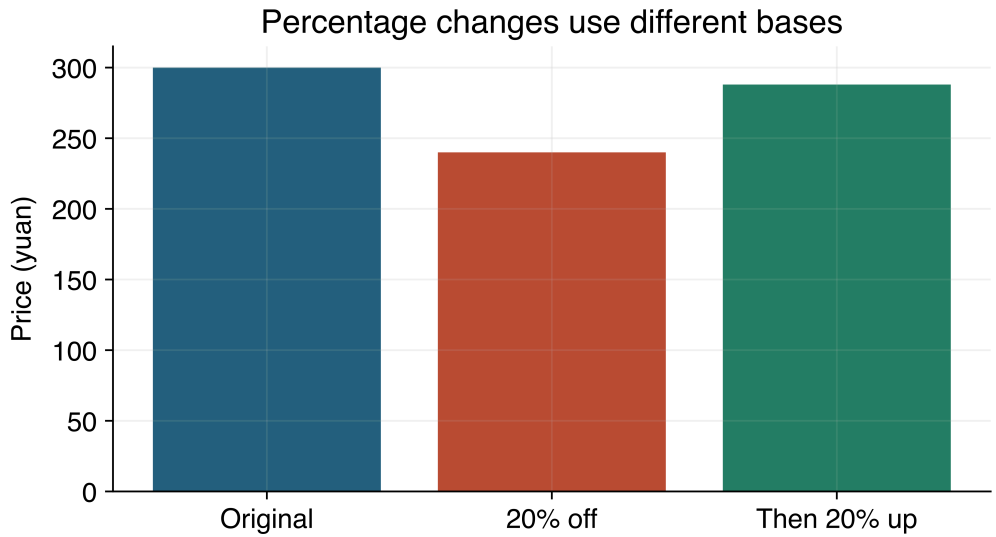


HCF reads the overlap's product; LCM everything's product (prime-factor Venns)

A two-set Venn diagram inside a universal-set rectangle: A left, B right, overlap centre, the complement region shaded, with the union, intersection, complement and n(A) operations annotated.

Percentages

Percentage means parts per 100: $35\% = 0.35 = \frac{7}{20}$. Percentages act as **multipliers** : increase by 12% means $\times 1.12$; decrease by 20% means $\times 0.8$. Reverse percentage divides the final value by the multiplier – June 2024 2HR Q8: a fridge priced at 6225 rupees after a 17% reduction originally cost $\frac{6225}{0.83} = 7500$ rupees. **Compound interest** and depreciation apply the multiplier repeatedly: $A = P\left(1 \pm \frac{r}{100}\right)^n$ – £2000 at 3% compound for 4 years grows to $2000 \times 1.03^4 =$ £2251.02; a car worth £12000 depreciating 15% per year for 3 years falls to $12000 \times 0.85^3 =$ £7369.50.



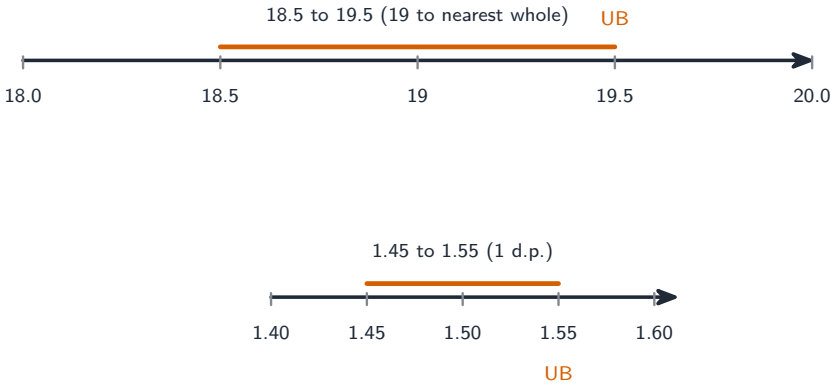
20% off then 20% up gives 288, not 300: the second 20% is of 240

Ratio and proportion

Ratio compares parts: simplify by dividing through ($45 : 60 = 3 : 4$); share by $\frac{\text{parts}}{\text{total}} \times$amount – £350 shared in the ratio 2 : 5 gives $\frac{2}{7} \times 350 =$ £100 and $\frac{5}{7} \times 350 =$ £250. **Proportion** scales within or between quantities: the unitary method finds one unit first (7 pens cost £4.20, so one pen costs £0.60 and 12 pens cost £7.20); quantities in **direct proportion** scale the same way ($y = kx$). Word problems mix ratio with fractions and percentages – keep the units explicit and check the answer is sensible.

Rounding, bounds, estimation and standard form

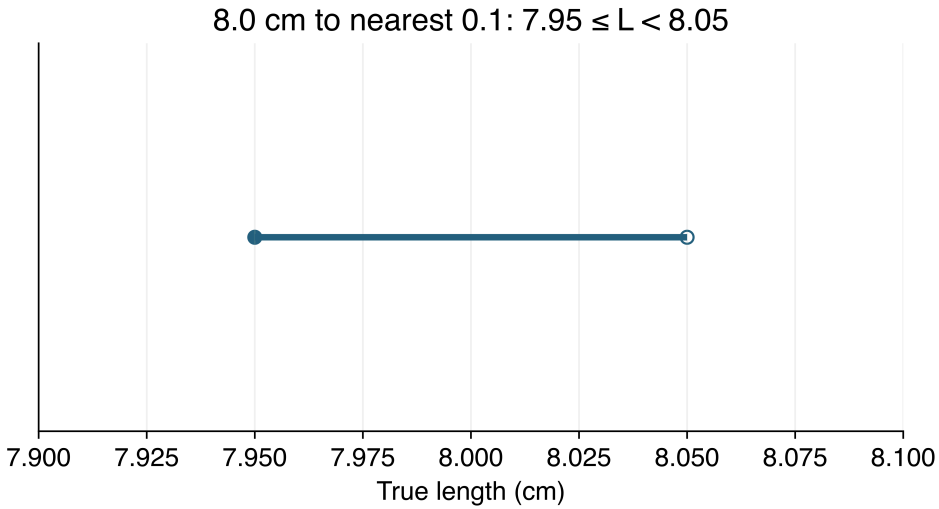
Round integers to powers of ten and decimals to significant figures or decimal places: $3.4617 \to 3.5$ (2 s.f.) and 3.46 (2 d.p.). An accurate value carries bounds – 19 to the nearest whole means $18.5 \le v < 19.5$ – the **upper bound** 19.5 and **lower bound** 18.5. Estimation rounds every number to 1 s.f. first: $\frac{4.12 \times 29.8}{0.187} \approx \frac{4 \times 30}{0.2} = 600$. Bound problems (Higher) choose the extremes the question needs – June 2024 2HR Q19: distance = speed × time with speed 19 km/h to the nearest whole (so UB 19.5) and time 1.5 h to 1 d.p. (so UB 1.55): the upper bound of the distance is $19.5 \times 1.55 = 30.2$ km (3 s.f.).



maximise distance: UB speed × UB time
$= \ 19.5 \times 1.55 \ = \ 30.2$ km (3 s.f.)

Bounds bar for 19 to the nearest whole (18.5 to 19.5) and 1.5 to 1 d.p. (1.45 to 1.55), with the upper-bound multiplication 19.5 x 1.55 = 30.2 marked.

Standard form writes $a \times 10^n$ with $1 \leq a < 10$: $604000 = 6.04 \times 10^5$ and $0.00007 = 7 \times 10^{-5}$ (June 2024 2HR Q9). Indices add and subtract across the multiplication and division of standard-form numbers, and the calculator's $\times 10^{\wedge}$ key keeps the working exact.



8.0 cm to the nearest 0.1 cm: $7.95 \leq L < 8.05$

Number in context: units, time and calculators

Everyday number – money, timetables, readings – uses the same arithmetic with units attached. Standard units: mass (kg, g), length (km, m, cm, mm), area, volume, time (seconds to years, 12- and 24-hour clocks), and the conversions between them ($1 \text{ m}^2 = 10^4 \text{ cm}^2$; 1 litre = 1000 cm^3). A scientific calculator applies the order of operations correctly – but rounding early loses accuracy: keep full precision through the working and round only the final answer, to the accuracy asked for.

Checklist

- Integers, ordering, directed numbers, four rules, BIDMAS, odd, even, prime, factors and multiples (F 1.1 A–H).
- Equivalent fractions, mixed numbers, common denominators, fraction of a quantity, reciprocals, FDP conversions (F 1.2 A–H).
- Recurring decimals to fractions by algebra (H 1.3 A; June 2024 2HR Q18).
- Decimals: place value, ordering, terminating decimals as fractions (F 1.3 A–E).
- Squares, cubes, roots, index laws, prime factorisation, HCF and LCM (F 1.4 A–E; June 2024 1HR Q11 family).
- Surds: simplifying, adding like surds, rationalising with conjugates (H 1.4 A–B; June 2024 1HR Q17 family).
- Sets: notation, universal/empty/complement, Venn diagrams; Higher subsets, n(A), algebraic and practical sets (F 1.5 A–E, H 1.5 A–D).
- Percentages: multipliers, percentage of, increase/decrease, reverse, compound interest and depreciation (F 1.6 A–G, H 1.6 A–B; June 2024 2HR Q8).
- Ratio in simplest form, sharing, direct proportion, word problems (F 1.7 A–E).
- Rounding to powers of ten, s.f. and d.p.; bound identification and bound problems choosing the right extremes; estimation by 1 s.f. (F 1.8 A–D, H 1.8 A; June 2024 2HR Q19).
- Standard form conversions and arithmetic (F 1.9 A, H 1.9 A; June 2024 2HR Q9).
- Everyday number, standard units and conversions, time calculations, calculator discipline (F 1.10 A–C, F 1.11 A).

Boundary notes: fractional, negative and zero indices beyond the multiplication and division laws belong to topic 2; proportion graphs belong to topics 2 and 4; compound measures (speed, density, pressure) belong to topic 4. Foundation candidates meet the Foundation rows only. Worked examples are adapted from the reviewed June 2024 papers or original; sheet questions are original unless labelled.

Equations, formulae and identities

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4MA1 topic 2 (specification Issue 2, November 2017). Foundation rows 2.1–2.4, 2.6–2.8 are shared with Higher; proportion (2.5) is Higher-only, and Higher extends manipulation to fractional **indices**, triple expansions, algebraic fractions, completing the square, proofs, linear–quadratic pairs and quadratic inequalities. On the June 2024 Higher papers this strand again carries the A/A* discriminators: an index equation, recurring-decimal proof, algebraic-fraction division, completing the square with a transformed minimum, and a quadratic inequality.

Must-know for topic 2 (Higher formulae sheet gives the **quadratic formula** only):

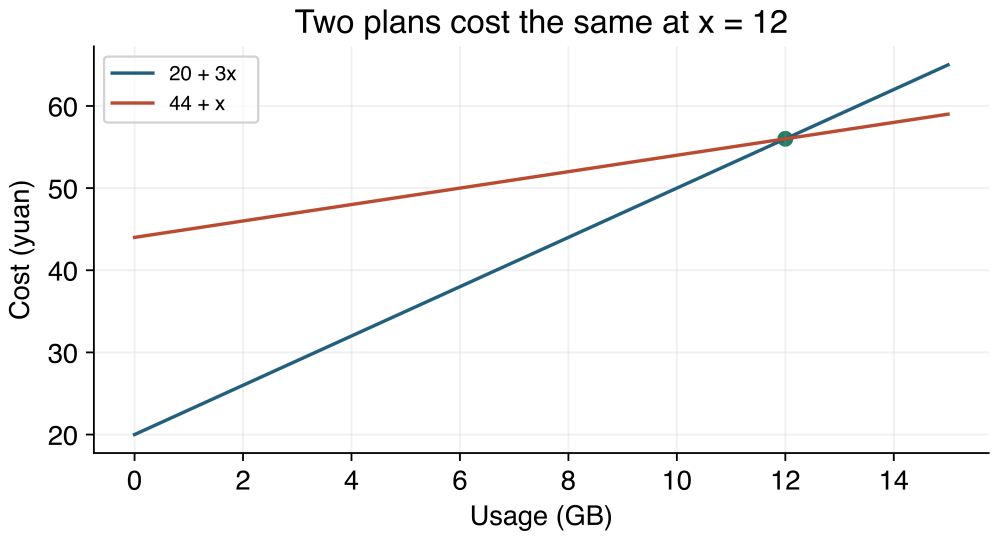
Family	Formulae
indices	$x^m \times x^n = x^{m+n}$, $x^m \div x^n = x^{m-n}$, $(x^m)^n = x^{mn}$, $x^0 = 1$, $x^{-n} = \dfrac{1}{x^n}$, $x^{1/2} = \sqrt{x}$
quadratics	$x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$; factoring, or $a(x+b)^2 + c$ by completing the square
proportion	$y \propto x^n \iff y = kx^n$; inverse $y = k/x^n$

Symbols, indices and expressions

Symbols represent unknown numbers in equations or **variables** in **expressions** and formulae; algebraic expressions follow the generalised rules of arithmetic. An **equation** asks which inputs work; an **identity** holds for every allowed input. **Index notation** covers positive, negative and zero powers: $a^3 = a \times a \times a$, $a^0 = 1$, $a^{-1} = \frac{1}{a}$, and Higher adds fractional powers: $x^{1/2} = \sqrt{x}$, $x^{1/3} = \sqrt[3]{x}$, $x^{2/3} = (\sqrt[3]{x})^2$. The **index laws** combine them: $x^m \times x^n = x^{m+n}$, $x^m \div x^n = x^{m-n}$, $(x^m)^n = x^{mn}$ – multiply means add the indices; divide means subtract.

> **Worked example (2HR June 2024 Q7, adapted).** $\dfrac{3^{n-2} \times 3^{n+5}}{3^{3n+10}} = 1$. Same base throughout, so the indices combine: $(n-2)+(n+5)-(3n+10) = 0$, which is $-n-7=0$. Hence $n=-7$. Never multiply the 3s – the bases match, so only the indices move.

Substitution evaluates expressions (negative and fractional values included); collecting **like terms**, multiplying a single term over a bracket, taking out **common factors** (factorise $x^2+10x+24 = (x+6)(x+4)$) and **expanding** the product of two linear expressions ($(x+8)(x-5) = x^2+3x-40$) are the Foundation toolkit. Higher extends expansion to three brackets: $(x+2)(x+3)(x-1) = (x^2+5x+6)(x-1) = x^3+4x^2+x-6$ – expand two first, then multiply through, and check with $x=0$ (**constant term** -6).



The plans cost the same where $20 + 3x = 44 + x$: $x = 12$, cost 56 yuan

Formulae and changing the subject

Use formulae from mathematics and other contexts, convert worded rules into symbols, and derive expressions from a situation. **Changing the subject** applies the same operation to both sides until the chosen letter stands alone: from $A = \pi r^2$, $r = \sqrt{A/\pi}$ (positive root – a length); from $v = u + at$, $t = \frac{v-u}{a}$.

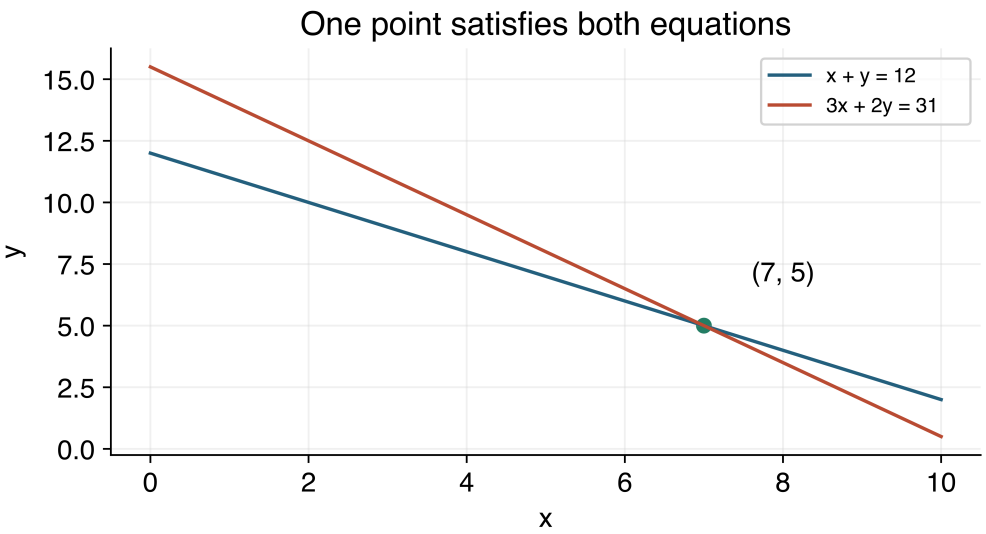
Higher cases put the subject deeper in the formula. From $V = \frac{4}{3}\pi r^3$: multiply by 3, divide by 4π, then cube-root: $r = \sqrt[3]{\frac{3V}{4\pi}}$. From $T = 2\pi\sqrt{l/g}$: square first – $T^2 = \frac{4\pi^2 l}{g}$ – so $l = \frac{gT^2}{4\pi^2}$. When the subject appears twice, collect its terms before factorising: $4a+3 = 5(a-r)$ expands to $4a+3 = 5a-5r$, so $a = 5r+3$. Check every rearrangement by substituting numbers into both versions.

Proportion (Higher): $y \propto x^n$ means $y = kx^n$ for a constant k; **inverse proportion** $y \propto 1/x^n$ means $y = k/x^n$. If $y \propto x^3$ and $y = 24$ when $x = 2$, then $k = 3$, so $y = 3x^3$ and $y = 81$ when $x = 3$. Graphically, $y = kx$ is a line through the **origin**; $y = k/x$ a **hyperbola** – the algebra and the graph must tell the same story.

Linear equations, proportion and simultaneous pairs

Solve linear equations with the unknown on either or both sides, integer or fractional **coefficients** – the moves are always expand, collect, divide: $7(x+3)=5x+8$ gives $7x+21=5x+8$, so $2x=-13$ and $x=-6.5$; the fractional form $\frac{4}{5}x+3=\frac{2}{3}$ multiplies through by 15: $12x+45=10$, so $x=-\frac{35}{12}$. Set up equations from given data: the three angles $a°, (a+10)°, (a+20)°$ of a triangle sum to 180, so $3a+30=180$ and $a=50$. Check by substitution, and keep solutions sensible for the context (a count cannot be negative or fractional).

Two **simultaneous linear equations** solve exactly by **elimination** or substitution: for $2x+3y=17$ and $3x-5y=35$, triple the first and double the second: $6x+9y=51$, $6x-10y=70$; subtracting gives $19y=-19$, so $y=-1$ and $x=10$. Check in the other equation: $3(10)-5(-1)=35$. ✓ Graphically each equation is a line and the common solution is their **intersection point** .



The solution is the crossing point: $x=7$, $y=5$ satisfies both equations

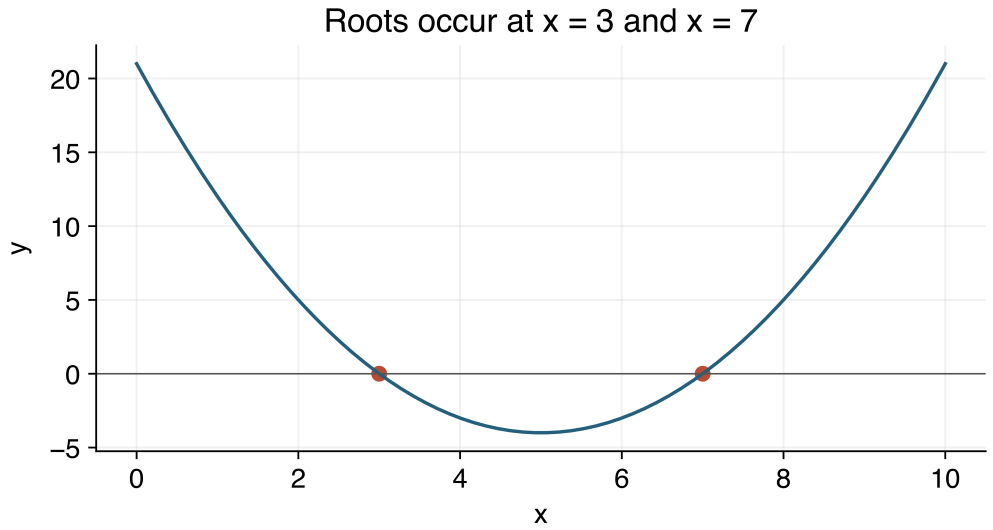
Quadratic algebra

A **quadratic expression** has the form ax^2+bx+c with $a\neq 0$. Foundation factorises x^2+bx+c; Higher factorises any: $6x^2-5x-6=(3x+2)(2x-3)$ – check by expanding ($6x^2-9x+4x-6$ ✓). **Difference of two squares** : $4x^2-9=(2x-3)(2x+3)$.

Algebraic fractions : factor first, then cancel whole factors, never parts of terms. Simplify $\dfrac{x^2+3x-10}{x^2+x-2}=\dfrac{(x+5)(x-2)}{(x+2)(x-1)}$ – no cancellation here (no shared factor); but $\dfrac{x^2-4}{x^2+5x+6}=\dfrac{(x-2)(x+2)}{(x+2)(x+3)}=\dfrac{x-2}{x+3}$. Adding uses a common denominator; dividing means multiplying by the **reciprocal** .

> **Worked example (2HR June 2024 Q26, adapted).** Write $4-(3x-5)\div\dfrac{3x^2+x-10}{4x-1}$ as a single fraction. First factor the quadratic: $3x^2+x-10=(3x-5)(x+2)$. Dividing by a fraction inverts it, and the $(3x-5)$ cancels:
>
> $$4-\frac{(3x-5)(4x-1)}{(3x-5)(x+2)}=4-\frac{4x-1}{x+2}=\frac{4(x+2)-(4x-1)}{x+2}=\frac{9}{x+2}$$

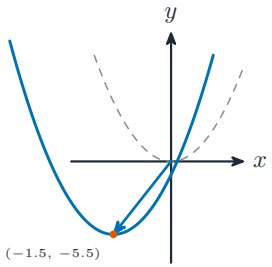
Proofs (Higher) use algebra, not examples. The classic **recurring decimal** : let $x=0.306306\ldots$; then $1000x=306.306\ldots$, and subtracting, $999x=306$, so $x=\frac{306}{999}=\frac{34}{111}$. State what x equals, multiply by a power of ten that shifts one full recurring block, subtract, simplify (June 2024 2HR Q18).



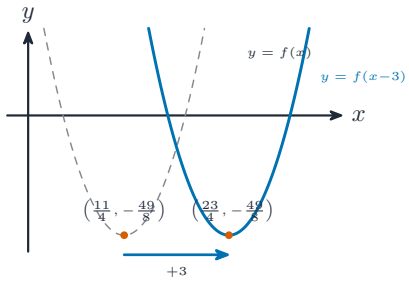
$x^2-10x+21=(x-3)(x-7)$: roots $x=3$ and $x=7$

Completing the square and solving quadratics

Completing the square rewrites $ax^2+bx+c=a(x+b')^2+c'$: half the x-coefficient gives the shift, inside the bracket, with its sign flipped. The **vertex** form exposes the minimum (for $a>0$) immediately: the graph of $y=a(x+b')^2+c'$ is $y=ax^2$ **translated** by $(-b', c')$.



dashed $y = 2x^2$, solid $y = 2(x+1.5)^2 - 5.5$; the vertex moves to $(-1.5, -5.5)$



inside the bracket acts on x, the other way

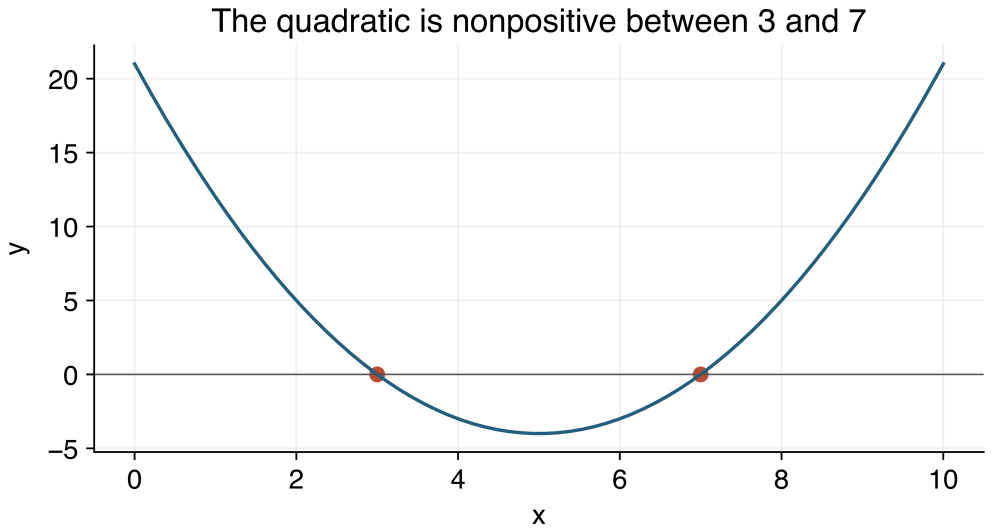
Left: completing the square moves the parabola - the vertex of y = 2x squared plus 6x minus 1 at x = -1.5. Right: the June 2024 Q20 minimum shifting right by 3 under f(x-3).

Worked example (1HR June 2024 Q20, adapted). (a) Write $2x^2 - 11x + 9$ in the form $a(x+b)^2 + c$: factor 2 from the x terms, half of $-\frac{11}{2}$ is $-\frac{11}{4}$, so

$$2x^2 - 11x + 9 = 2\left(x - \tfrac{11}{4}\right)^2 - \tfrac{121}{8} + 9 = 2\left(x - \tfrac{11}{4}\right)^2 - \tfrac{49}{8}$$

(b) The graph of $y = f(x-3)$ shifts f three units right, so the minimum moves from $\left(\frac{11}{4}, -\frac{49}{8}\right)$ to $\left(\frac{23}{4}, -\frac{49}{8}\right) = (5.75, -6.125)$. Inside the bracket acts on x, and the other way.

Solving quadratics: by factorisation $(x^2+x-30 = (x+6)(x-5) = 0$ gives $x = -6$ or $5)$; by the quadratic formula $x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$ when factorising fails – for $2x^2 + 6x - 1 = 0$, $x = \frac{-6 \pm \sqrt{36+8}}{4} = \frac{-3 \pm \sqrt{11}}{2}$; or by completing the square, which solves and gives the vertex at once. Form equations from context (area, Pythagoras, projectile-style $h = at^2 + bt + c$), keep exact answers unless told otherwise, and reject **roots** the context forbids.

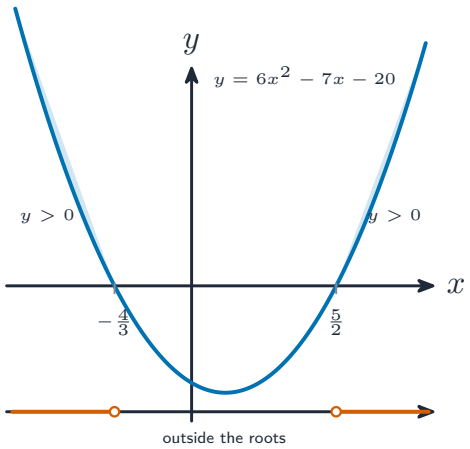


$x^2 - 10x + 21 = (x-3)(x-7) \leq 0$ *for* $3 \leq x \leq 7$

Inequalities and linear–quadratic pairs

Inequality symbols $<, >, \leq, \geq$ (double-ended forms like $1 < x \leq 5$ included) describe intervals; open and closed circles on a **number line** mark excluded and included ends. Solving a **linear inequality** mirrors equation moves – except multiplying or dividing by a negative flips the direction: $7 - x \leq 5$ gives $-x \leq -2$, so $x \geq 2$.

Quadratic inequalities (Higher) need the **critical values** , then the sign of the **parabola** between them: a positive quadratic is above zero outside its roots.



positive quadratic: $>$ holds
outside the critical values

The June 2024 Q20 parabola $y = 6x$ squared minus $7x$ minus 20 with roots -4/3 and 5/2 marked, the above-axis arcs shaded, and the outside ranges shaded on a number line below.

> **Worked example (2HR June 2024 Q20, adapted).** Solve $6x^2 - 7x - 20 > 0$. Factorise: $(3x + 4)(2x - 5) > 0$, so the critical values are $x = -\frac{4}{3}$ and $x = \frac{5}{2}$. The parabola opens upward – positive outside the roots – so $x < -\frac{4}{3}$ or $x > \frac{5}{2}$, marked on the number line with open circles (the values themselves give 0, not > 0). Sketch the parabola first; the picture decides inside vs outside.

Linear–quadratic pairs (Higher): substitute the linear equation into the quadratic. For $y = 2x - 11$ with $x^2 + y^2 = 25$: $x^2 + (2x - 11)^2 = 25$ gives $5x^2 - 44x + 96 = 0$, and by formula $x = \frac{44 \pm \sqrt{1936 - 1920}}{10} = \frac{44 \pm 4}{10} = 4.8$ or 4, giving $(4.8, -1.4)$ and $(4, -3)$; both satisfy the circle. For $y = 11x - 2$ with $y = 5x^2$: $5x^2 - 11x + 2 = (5x - 1)(x - 2) = 0$, so $\left(\frac{1}{5}, 0.2\right)$ and $(2, 20)$. Retain both solutions unless the context removes one.

Regions (F 2.8 D–E, harder cases Higher): on a Cartesian grid, each linear inequality bounds a **half-plane** ; test one point per boundary (the origin is handy unless it lies on a boundary), then shade the region satisfying every condition – for example $x \geq 0$, $y \geq 1$, $x + y \leq 5$ gives the interior of a triangle with vertices $(0, 1)$, $(0, 5)$, $(4, 1)$.

Checklist

- Use symbols, index laws (integer, then fractional/negative/zero – Higher) and combine indices on one **base** (F 2.1, H 2.1; June 2024 2HR Q7).
- Substitute, collect terms, expand single and double brackets – and Higher, triple brackets – factorise common factors and quadratics (F 2.2, H 2.2 A–B).
- Derive, use and rearrange formulae, including subject-twice and power cases; set up and solve direct/inverse proportion (F 2.3, H 2.3, H 2.5).
- Solve linear equations from data and exact simultaneous pairs by elimination, interpreting the pair as intersecting lines (F 2.4, F/H 2.6).
- Manipulate algebraic fractions: factor, cancel, common denominators, invert to divide (H 2.2 C; June 2024 2HR Q26).
- Construct algebraic proofs, including recurring-decimal conversions (H 2.2 E; June 2024 2HR Q18).
- Complete the square, read the vertex form, and solve quadratics by factorising, formula or square – including from context (H 2.2 D, H 2.7 A–C; June 2024 1HR Q20).
- Solve linear and quadratic inequalities with number-line solution sets; identify bounded regions from linear inequalities (F 2.8, H 2.8; June 2024 2HR Q20).
- Solve linear–quadratic simultaneous pairs by substitution, keeping both points (H 2.7 D).

Boundary notes: the **discriminant** as a named tool and factor theorem are beyond the 4MA1 list – solving uses factorising, the formula or completing the square; **surd** rationalisation appears at Higher (rationalise $\frac{7}{4(2-\sqrt{3})}$-style denominators by multiplying top and bottom by the **conjugate** , e.g. to $\frac{14+7\sqrt{3}}{4}$). Foundation meets 2.1–2.4, 2.6–2.8 only. Worked examples above are adapted from the reviewed June 2024 Higher pair (see the meta's assessment evidence); sheet questions are original unless labelled.

Sequences, functions and graphs

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4MA1 topic 3 (specification Issue 2, November 2017). Foundation rows 3.1 and 3.3 are shared with Higher; the function-notation block 3.2 and the calculus block 3.4 are Higher-only, and Higher 3.3 extends the graphs work to cubics, reciprocals, trig curves, transformations and intersections. On the June 2024 Higher papers this strand is the heaviest of the six topics (about a third of each paper) and carries the A/A* discriminators: algebraic series sums, composite functions, perpendicular lines, line–curve intersections and stationary points.

Must-know for topic 3 (Higher formulae sheet gives the series and trapezium rules only):

Family	Formulae
arithmetic	$u_n = a + (n-1)d$, $S_n = \frac{n}{2}[2a + (n-1)d] = \frac{n}{2}(a + u_n)$
functions	$\mathrm{fg}(x) = f(g(x))$ – do g first; f^{-1} undoes f on a one-to-one domain
lines	gradient $m = \dfrac{y_2 - y_1}{x_2 - x_1}$; parallel $m_1 = m_2$; perpendicular $m_1 m_2 = -1$
intersections	$y_1 = y_2 \iff y_2 - y_1 = 0$ – solve, then substitute back
calculus	$\dfrac{d}{dx}(ax^n) = anx^{n-1}$; stationary where $\dfrac{dy}{dx} = 0$

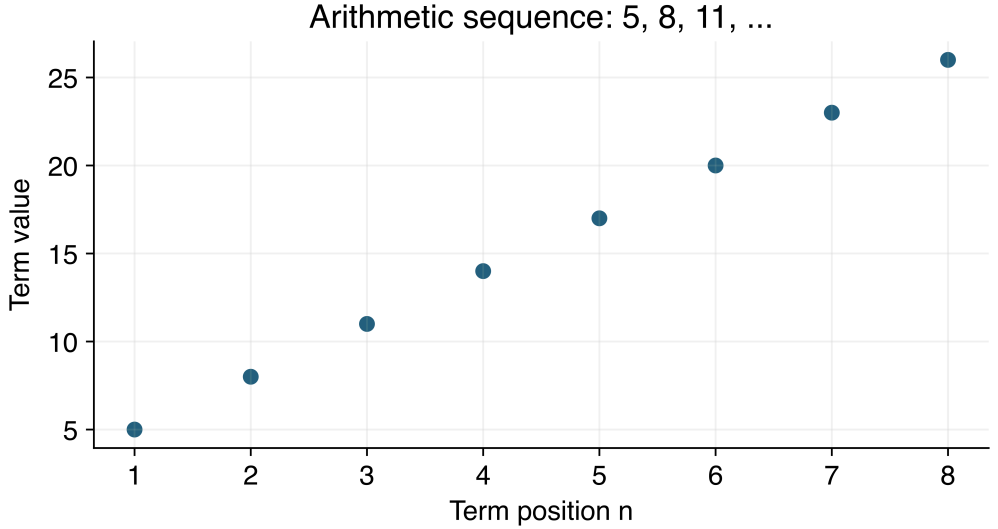
Sequences and series

A **term-to-term rule** says how to get the next term (add 4: 5, 9, 13, 17, …; multiply by 2: 1, 2, 4, 8, …); a **position-to-term rule** gives a term directly from its position. For an **arithmetic sequence** with first term a and **common difference** d, the nth term is $u_n = a + (n-1)d$: for 1, 3, 5, 7, … the rule is $2n - 1$, and "nth term is $4n + 3$" generates 7, 11, 15, … Check a proposed rule on two positions before trusting it.

Higher adds the **sum of an arithmetic series**. Pairing first with last, second with second-last, … gives $n/2$ equal pair-sums of $a + u_n$:

$$S_n = \frac{n}{2}[2a + (n-1)d] = \frac{n}{2}(a + u_n)$$

For $4 + 7 + 10 + 13 + \cdots$: $a = 4$, $d = 3$, so $S_{50} = 25\,(8 + 49 \times 3) = 25 \times 155 = 3875$. Recovering a and d from two terms uses the term rule as simultaneous equations: if $u_2 = 7$ and $u_5 = 19$, then $3d = 12$, so $d = 4$ and $a = 7 - 4 = 3$.



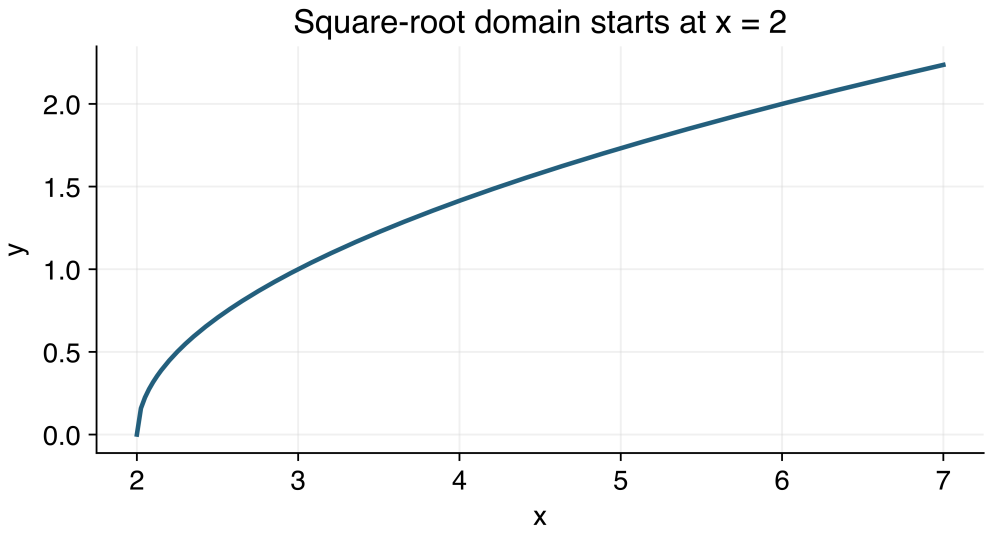
Add 3 each time: nth term 3n + 2, so the eighth term is 26

> **Worked example (1HR June 2024 Q23, adapted).** Three consecutive terms of an arithmetic series are $4x-14$, $x+2$ and $7x-9$. Consecutive terms carry a common difference, so $(x+2)-(4x-14) = (7x-9)-(x+2)$, giving $-3x+16 = 6x-11$, so $x = 3$. The terms are $-2, 5, 12, \ldots$: $a = -2$, $d = 7$. Then $S_{40} = 20\,[2(-2) + 39 \times 7] = 20 \times 269 = 5380$. Keep a, d symbolic until the final substitution – the algebra, not the arithmetic, carries the marks.

Function notation

A **function** maps each input of one set to exactly one output of another: write $f(x) = \ldots$ or $f\colon x \mapsto \ldots$ The **domain** is the set of allowed inputs; the **range** is the set of outputs. Exclude inputs that break the rule: for $f(x) = \dfrac{1}{x-2}$ exclude $x = 2$; for $f(x) = \sqrt{x}$ take $x \geq 0$.

The **composite function** $\mathrm{fg}(x) = f(g(x))$ applies g first, then f – the output of g must be an allowed input of f. The **inverse function** f^{-1} undoes f, and exists only where f is one-to-one: for $f(x) = \sqrt{x-2}$ (domain $x \geq 2$, range $f \geq 0$), writing $y = \sqrt{x-2}$ and squaring gives $x = y^2 + 2$, so $f^{-1}(x) = x^2 + 2$ on domain $x \geq 0$. Always check $f^{-1}(f(x)) = x$.



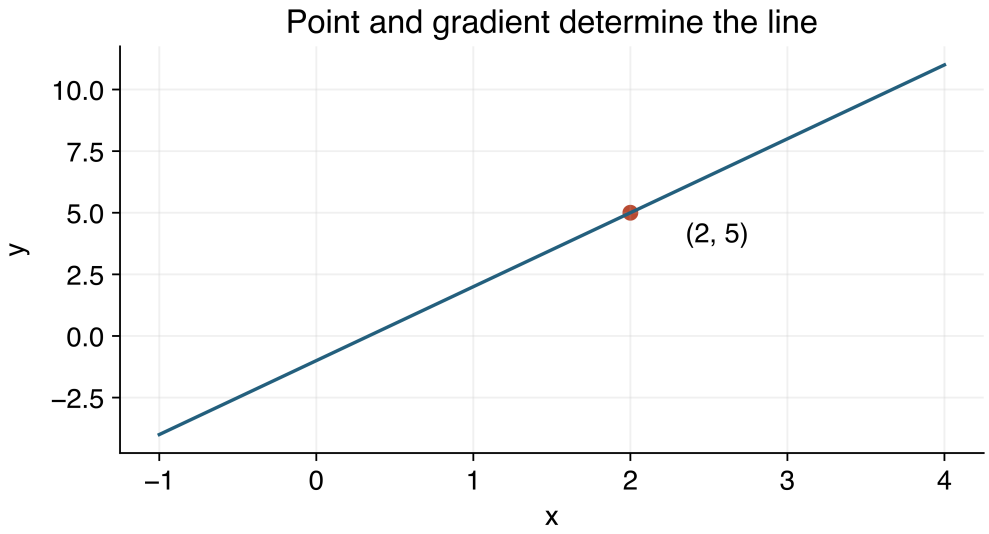
$y = \sqrt{(x-2)}$ is defined only for $x \geq 2$

> **Worked example (2HR June 2024 Q17, adapted).** $f(x) = \dfrac{x}{2x-4}$ and $g(x) = 3x+1$; find k given $\mathrm{fg}(k) = 2$. First $g(k) = 3k+1$, then
>
> $$\mathrm{fg}(k) = f(3k+1) = \frac{3k+1}{2(3k+1)-4} = \frac{3k+1}{6k-2} = 2$$
>
> so $3k+1 = 12k-4$, giving $9k = 5$ and $k = \frac{5}{9}$. (Shortcut worth knowing: solving $f(x) = 2$ first gives $x = 8/3$, so set $g(k) = 8/3$ – same answer with less algebra.)

Coordinates and straight lines

Cartesian coordinates name points in all four quadrants; a **midpoint** averages the end coordinates: $M = \left(\frac{x_1+x_2}{2}, \frac{y_1+y_2}{2}\right)$. The **gradient** of a straight line is change in y divided by change in x: through $(1,7)$ and $(2,9)$ the gradient is 2. A line $y = mx + c$ has gradient m and crosses the y-axis at $(0, c)$ – for $y = 3x + 5$, gradient 3 and intercept $(0,5)$. Special cases: $x = k$ is vertical (no finite gradient), $y = c$ is horizontal (gradient 0). Conversion graphs (currency, temperature) are read the same way.

Interpreting real graphs is part of this block: on a distance–time graph the gradient is speed; on a speed–time graph the gradient is acceleration and the area under the graph is distance travelled. Plotting practice covers filling tables of values for straight lines (including forms $ax + by = c$) and quadratics, drawing a smooth curve through plotted points – never line segments between them.



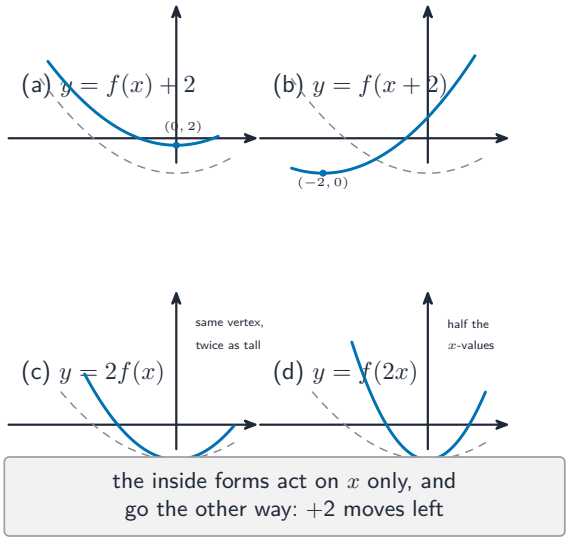
Gradient 3 through (2, 5): $y - 5 = 3(x-2)$, so $y = 3x - 1$

Parallel lines share a gradient. **Perpendicular lines** have gradients multiplying to -1: perpendicular to m is $-1/m$. The line through (x_1, y_1) with gradient m is $y - y_1 = m(x - x_1)$.

> **Worked example (2HR June 2024 Q21, adapted).** $ABCD$ is a square with $A(-5,2)$ and $B(3,5)$; find the equation of BC in the form $ax+by+c=0$. Adjacent square sides are perpendicular. Gradient of AB is $\frac{5-2}{3-(-5)} = \frac{3}{8}$, so gradient of BC is $-\frac{8}{3}$. Through $B(3,5)$: $y - 5 = -\frac{8}{3}(x-3)$, so $3y - 15 = -8x + 24$, giving $8x + 3y - 39 = 0$. Multiply out at the end so a, b, c are integers, as asked.

Graphs and transformations

Higher 3.3 expects recognition and plotting of three curve families beyond quadratics: cubics $y = Ax^3 + Bx^2 + Cx + D$ (any signs; $y = x^3 - 4x$ rises–falls–rises), reciprocals $y = A/x$, $y = A/x^2$, $y = A/x^3$ (two branches, asymptotes, never crossing the axes) and the trigonometric graphs $y = \sin x$, $y = \cos x$, $y = \tan x$ for angles of any size in degrees – sine and cosine oscillate between -1 and 1 with period 360°; tangent repeats every 180° and breaks at $90° + 180°n$. A circle centred at the origin has $x^2 + y^2 = r^2$ – the circle enters this course as the second curve of an intersection question.



The four required transformations of a parabola - translate up, translate left, stretch vertically, compress horizontally - each drawn against the dashed original.

Four **transformations** of $y = f(x)$ are required, for linear, quadratic, sine and cosine functions:

Form	**Effect on** $y = f(x)$
$y = f(x) + a$	translate by a vertically (up if $a > 0$)
$y = f(x + a)$	translate by $-a$ horizontally (left if $a > 0$)
$y = af(x)$	vertical stretch, scale factor a
$y = f(ax)$	horizontal stretch, scale factor $1/a$

The inside forms act "backwards" on x and only on x. For $f(x) = x^2$: $y = f(x-2)+5 = (x-2)^2 + 5$ moves the minimum from $(0, 0)$ to $(2, 5)$; $y = f(2x) = 4x^2$ halves the x-values, making the parabola narrower, not taller. For $y = \sin 2x$ the period halves to 180°. Read a drawn transformation off the graph (where did the turning point go?) and write it algebraically – both directions are assessed.

Gradients of curves: draw a tangent at the point and take its gradient as rise/run – the drawn line, not the curve, is measured. Exact curve gradients need calculus (next section).

Intersections: the x-values where a linear y_1 meets a non-linear y_2 are the solutions of $y_2 - y_1 = 0$. Meeting points of $y = 2x + 1$ and $y = x^2 + 3x - 2$ solve $x^2 + x - 3 = 0$; of $y = 5$ and $y = x^3 - 3x^2 + 7$, solve $x^3 - 3x^2 + 2 = 0$.

> **Worked example (2HR June 2024 Q22, adapted).** Find where the line $y = 3x - 1$ meets the curve $x^2 + y^2 = y + 11$. Substitute the line into the curve:

$$x^2 + (3x-1)^2 = (3x-1) + 11 \;\Rightarrow\; 10x^2 - 9x - 9 = 0 \;\Rightarrow\; (5x+3)(2x-3) = 0$$

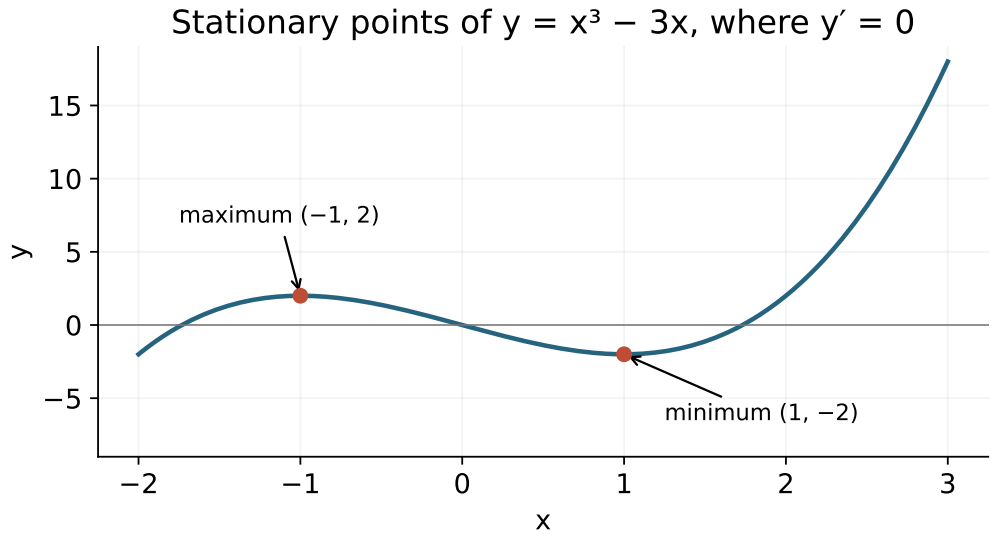
so $x = -\frac{3}{5}$ or $x = \frac{3}{2}$, with $y = 3x - 1$ giving $y = -\frac{14}{5}$ or $y = \frac{7}{2}$. The points are $\left(-\frac{3}{5}, -\frac{14}{5}\right)$ and $\left(\frac{3}{2}, \frac{7}{2}\right)$ – substitute back into the *other* equation to check: $\frac{9}{4} + \frac{49}{4} = \frac{58}{4} = 14.5 = \frac{7}{2} + 11$. ✓

Differentiation and stationary points

The **gradient of a curve** varies along it: a **variable rate of change** . **Differentiation** gives it exactly: for integer powers of x,

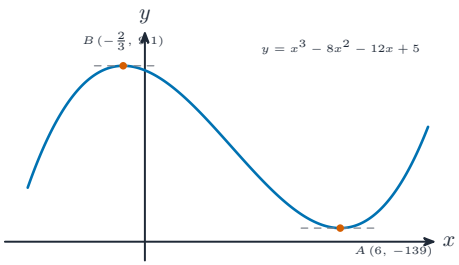
$$y = ax^n \;\Rightarrow\; \frac{dy}{dx} = anx^{n-1}, \qquad \text{term by term}$$

For $y = x^3 - 8x^2 - 12x + 5$: $\frac{dy}{dx} = 3x^2 - 16x - 12$. A **stationary point** has $\frac{dy}{dx} = 0$: here $3x^2 - 16x - 12 = (3x+2)(x-6)$, so $x = -\frac{2}{3}$ or $x = 6$. Distinguish **maximum** from **minimum** from the graph's shape: a cubic with positive x^3 coefficient rises–falls–rises... here $y \to -\infty$ as $x \to -\infty$, so the left stationary point $x = -\frac{2}{3}$ is the maximum ($y = \frac{247}{27} \approx 9.1$) and the right one is the minimum ($y(6) = 216 - 288 - 72 + 5 = -139$).

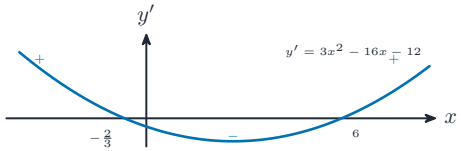


$y' = 3x^2 - 3 = 0$ at $x = \pm 1$: maximum $(-1, 2)$, minimum $(1, -2)$

Worked example (1HR June 2024 Q19, adapted). C has equation $y = x^3 - 8x^2 - 12x + 5$ and exactly two stationary points A and B with $x_A > x_B$; find A. Differentiate and set to zero: $(3x + 2)(x - 6) = 0$, and the larger root is $x = 6$. Substituting into the curve: $y = 216 - 288 - 72 + 5 = -139$, so $A = (6, -139)$. Marks follow the chain – differentiate (at least two terms right), set to zero, solve the quadratic, substitute back.



stationary where $\frac{dy}{dx} = 0$: $x = -\frac{2}{3}$ or 6



+ to − at B: maximum;
− to + at A: minimum

The June 2024 Q19 cubic y = x cubed minus 8 x squared minus 12 x plus 5, with the maximum near x = -0.67, y = 9.1 and the minimum A(6, -139) marked, tangent-horizontal cross marks at both.

Kinematics: with displacement s in metres after t seconds, velocity is the rate of change of displacement and acceleration the rate of change of velocity: $v = \dfrac{ds}{dt}$, $a = \dfrac{dv}{dt} = \dfrac{d^2s}{dt^2}$. For $s = t^3 - 24t$ (metres, $0 \le t \le 20$): $v = 3t^2 - 24$ m/s and $a = 6t$ m/s^2. The particle is instantaneously at rest where $v = 0$: $t = \sqrt{8} = 2.83$ s (3 s.f.).

Checklist

- Generate sequences from term-to-term and position-to-term rules; find the rule of an integer sequence (F 3.1 A–B).
- Use $u_n = a + (n - 1)d$ for arithmetic sequences; find a and d from any two terms (F 3.1 C, H 3.1 A–B).
- Sum an arithmetic series with $S_n = \frac{n}{2}[2a + (n - 1)d]$, including algebraic terms (H 3.1 C; June 2024 1HR Q23).
- Use $f(x)$ and $f\colon x \mapsto$ notation; state domains with exclusions and ranges (H 3.2 A–C).
- Build fg(x) – g first – and find f^{-1} on a one-to-one domain (H 3.2 D; June 2024 2HR Q17).
- Read, plot and interpret graphs in all quadrants: midpoints, conversion graphs, distance/speed–time graphs, tables of values (F 3.3 A–I).
- Gradients from two points; $y = mx + c$; equations of parallel and perpendicular lines through a point (F 3.3 G–H, H 3.3 F–G; June 2024 2HR Q21).
- Recognise and sketch cubics, reciprocal curves, sin / cos / tan, and the origin-centred circle $x^2 + y^2 = r^2$ (H 3.3 A).
- Apply and read off the four transformations $f(x) + a$, $f(x + a)$, $af(x)$, $f(ax)$ (H 3.3 B–C).
- Estimate a curve's gradient by drawing a tangent (H 3.3 D).
- Solve linear–non-linear intersections via $y_2 - y_1 = 0$ and check by substitution (H 3.3 E; June 2024 2HR Q22).
- Differentiate integer powers; find stationary points; classify max/min from the graph shape (H 3.4 A–D; June 2024 1HR Q19).
- Apply calculus to motion: $v = ds/dt$, $a = dv/dt$, and "at rest" means $v = 0$ (H 3.4 E).

Boundary notes: geometric series and sum-to-infinity are excluded at this level (no geometric rows in 4MA1 3.1); differentiation is limited to integer powers of x – chain, product and quotient rules are excluded; radian measure is excluded (degrees throughout). Foundation candidates meet 3.1 and 3.3 only. Worked examples above are adapted from the reviewed June 2024 Higher pair (see the meta's assessment evidence); all other questions on the sheets are original.

Geometry and trigonometry

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4MA1 topic 4 (specification Issue 2, November 2017) is the largest topic: Foundation rows 4.1–4.11 cover angle facts, polygons, measures, constructions, circle language, Pythagoras and 2D trigonometry, mensuration and similarity; Higher adds the intersecting chord properties, the full circle-theorem reasoning programme, obtuse-angle and non-right-angled trigonometry, 3D problems, sectors, cones, spheres and the k^2/k^3 similarity ratios. On the June 2024 Higher papers this strand supplied the multi-step AO3 chains: a reasoned circle-theorem chase, a composite hexagon area, a 3D cosine-rule angle and a k^3 similar-solids equation.

Must-know for topic 4 (Higher formulae sheet gives the sine/cosine rules, ½ab sin C, and the cone/sphere volume and surface formulae):

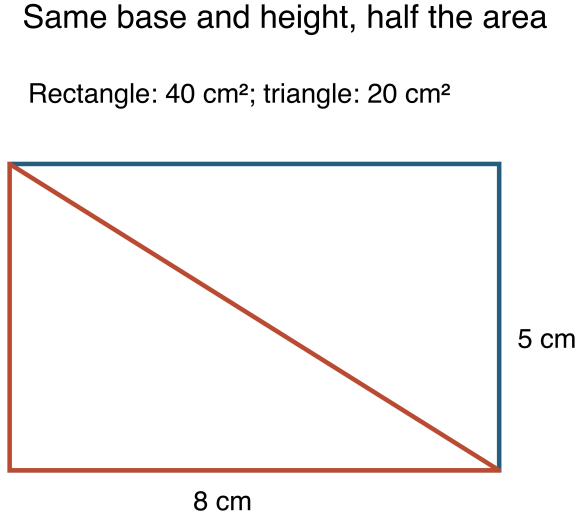
Family	Formulae
triangles	$a^2 = b^2 + c^2 - 2bc\cos A$; $\dfrac{a}{\sin A} = \dfrac{b}{\sin B}$; area $= \frac{1}{2}ab\sin C$
circle	arc $= \frac{\theta}{360} \times 2\pi r$; sector area $= \frac{\theta}{360} \times \pi r^2$ (θ in degrees)
solids	cylinder $V = \pi r^2 h$; cone $V = \frac{1}{3}\pi r^2 h$; sphere $V = \frac{4}{3}\pi r^3$, $SA = 4\pi r^2$
similarity	lengths k : areas k^2 : volumes k^3

Angles, polygons and symmetry

Angles classify as acute ($< 90°$), right, obtuse ($90°$–$180°$) and reflex ($> 180°$). Angles on a straight line sum to 180°, around a point to 360°, vertically opposite angles are equal, and parallel lines give equal **corresponding angles** and **alternate angles** (allied angles sum to 180°). The exterior angle of a triangle equals the sum of the two remote interior angles, and the angle sum is 180°; an isosceles triangle has two equal sides and base angles, an equilateral three of each at 60°.

Polygons carry names by side count; a **quadrilateral** has an angle sum of 360°, and each polygon's interior angles sum to $(n-2) \times 180°$. A **regular polygon** has all sides and angles equal: exterior angle $= 360°/n$, interior $= 180° - 360°/n$ – a regular pentagon has interior angles of 108°. The special quadrilaterals nest: parallelogram (opposite sides and angles equal, diagonals bisect), rectangle (also right angles), rhombus (also all sides equal, diagonals perpendicular), square, kite, trapezium (one parallel pair). Two figures are **congruent** when identical in shape and size (conditions SSS, SAS, ASA, RHS); **similar** figures have equal angles with corresponding sides in ratio.

A shape's **line of symmetry** reflects it onto itself; its **order of rotational symmetry** is the number of self-matches in one turn (a rectangle: 2 lines, order 2; a regular hexagon: 6 lines, order 6).



Rectangle $8 \times 5 = 40$ cm^2; the triangle with the same base and height is half: 20 cm^2

Measures, bearings and compound rates

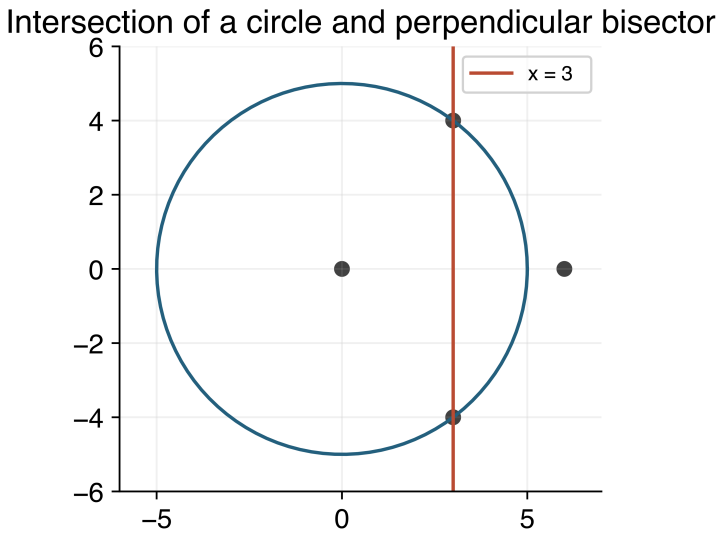
Read instrument scales sensibly and estimate before computing; time intervals work in both 12- and 24-hour clocks. An angle measure includes **three-figure bearings** : measured clockwise from north, written as three digits – 040°, not 40°. The return bearing reverses: if Q bears 040° from P, then P bears 220° from Q (add 180°, taking the answer mod 360).

Average **speed** is distance over time; **density** is mass over volume; **pressure** is force over area – all one family of **compound measures** : fix the unit vocabulary (km/h, g/cm^3, N/m^2) and convert carefully. A car covering 234 km in 2 h 36 min averages $234 \div 2.6 = 90$ km/h.

Constructions and scale drawings

Measure and draw lines to the nearest millimetre; construct triangles from SSS, SAS or ASA with ruler and protractor. With **straight edge and compasses** construct (i) the perpendicular bisector of a line segment and (ii) the bisector of an angle; these also build specific angles (60° from an equilateral arc construction, 90° by perpendicular, 45° by bisecting). Constructions answer **locus** questions: the set of points a fixed distance from a point (circle), from a line (parallel pair), equidistant from two points (perpendicular bisector) or from two lines (angle bisector) – shade the region satisfying several conditions at once.

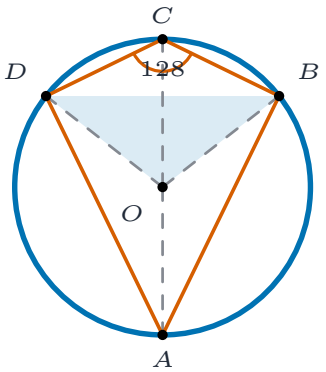
Scale drawings and maps carry a ratio (1 : 50 000): convert map distance to real distance through the scale factor, keeping units explicit.



Points 5 from O and equidistant from (0, 0) and (6, 0): $x = 3$ meets the circle at $(3, \pm 4)$

Circle geometry with reasons

Circle language: centre, radius, diameter, **chord** , circumference, **tangent** (touches at one point, perpendicular to the radius there), arc, sector, segment. Foundation uses chord and tangent properties informally; Higher requires the full programme with standard reasons. The **cyclic quadrilateral** has opposite angles summing to 180°; the angle at the centre is twice the angle at the circumference on the same arc; angles in the same segment are equal; the angle in a semicircle (standing on a diameter) is a right angle; and the angle between a tangent and a chord equals the angle in the alternate segment (the alternate segment theorem). Chord properties: the perpendicular from the centre bisects the chord; two intersecting chords satisfy $AE \times EB = CE \times ED$, and the internal/external versions power this family.



cyclic quad: $\angle BAD = 52$

centre $= 2\times$ rim: $\angle BOD = 104$

$OB = OD$ (radii): isosceles

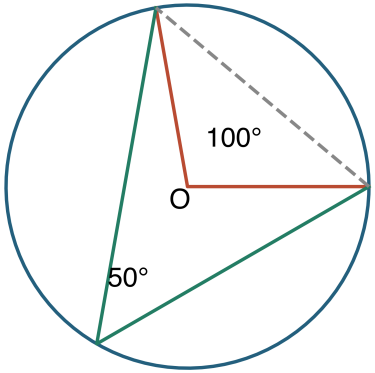
$\angle OBD = \frac{180-104}{2} = 38$

every numerical step names its reason

The June 2024 Q13 configuration: a circle centre O with cyclic quadrilateral ABCD, angle BCD marked 128 degrees, and the chain BAD = 52, BOD = 104, OBD = 38 written beside it.

Worked example: 1HR June 2024 Q13, adapted. A, B, C, D lie on a circle centre O with $\angle BCD = 128°$; find $\angle OBD$. Opposite angles of the cyclic quadrilateral sum to 180°, so $\angle BAD = 180 - 128 = 52°$. The angle at the centre is twice the angle at the circumference on the same arc: $\angle BOD = 104°$. Triangle OBD is isosceles ($OB = OD$, radii), so $\angle OBD = \frac{180-104}{2} = 38°$. Every numerical step names its reason – that is what the marks list pays for.

The centre angle is twice the circumference angle



The angle at the centre is twice the angle at the circumference: 100° and 50°

Pythagoras and trigonometry in 2D

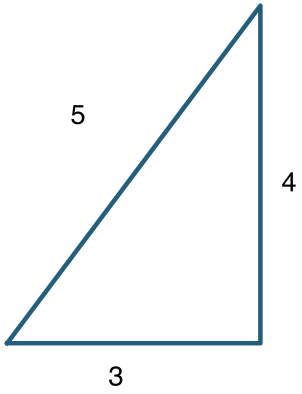
Pythagoras' theorem : $a^2 + b^2 = c^2$ in right-angled triangles (6-8-10 is a whole-number triple; 5-12-13 another). SOH CAH TOA gives $\sin\theta = \frac{\text{opp}}{\text{hyp}}$, $\cos\theta = \frac{\text{adj}}{\text{hyp}}$, $\tan\theta = \frac{\text{opp}}{\text{adj}}$ – used forwards for sides and backwards (Shift-sin) for angles. The **angle of elevation** rises from the horizontal, the **angle of depression** falls from it (alternate angles carry it into the triangle).

Higher extends the ratios to **obtuse angles**: $\sin 130° = \sin 50°$ (sine stays positive), $\cos 130° = -\cos 50°$ (cosine turns negative). Any triangle now yields to the **sine rule** $\dfrac{a}{\sin A} = \dfrac{b}{\sin B}$ (a pair – side over opposite angle – plus one more part) or the **cosine rule** $a^2 = b^2 + c^2 - 2bc\cos A$ (two sides and the included angle, or three sides), and the area formula $\frac{1}{2}ab\sin C$ works in reverse: area 15 with $a = 6$, $b = 10$ gives $\sin C = \frac{2\times 15}{60} = 0.5$, so $C = 30°$ (or 150° if the diagram shows an obtuse angle).

> **Worked example: sine rule.** In triangle ABC, $\angle A = 40°$, $\angle B = 65°$ and $a = BC = 8$ cm. Find $b = AC$. Use the pair side-over-opposite-angle twice:
>
> $$\frac{b}{\sin 65°} = \frac{8}{\sin 40°} \;\Rightarrow\; b = \frac{8\sin 65°}{\sin 40°} = 11.3 \text{ cm}.$$

> **Worked example: cosine rule with an obtuse angle.** Two sides 7 cm and 9 cm meet at 110°. Find the third side a:
>
> $$a^2 = 7^2 + 9^2 - 2(7)(9)\cos 110° = 130 + 43.1 = 173.1, \qquad a = 13.2 \text{ cm}.$$
>
> Because $\cos 110°$ is negative, the last term is **added**; the side opposite an obtuse angle is the longest. Check the calculator is in degree mode.

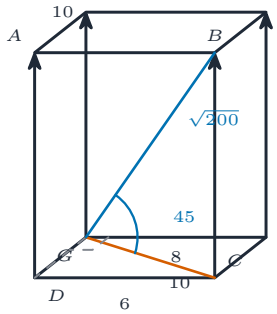
Label the known sides before choosing a rule



Label opposite, adjacent and hypotenuse first: 3, 4 and 5 here

Trigonometry in three dimensions

3D problems are 2D problems inside a solid: name the right triangle, then Pythagoras or trigonometry as usual. In a cuboid with base 6 cm × 8 cm and height 10 cm, the base diagonal is $\sqrt{6^2 + 8^2} = 10$ cm, and the **space diagonal** is $\sqrt{6^2 + 8^2 + 10^2} = \sqrt{200} \approx 14.1$ cm; the angle between the space diagonal and the base diagonal satisfies $\tan\theta = \frac{10}{10}$, so $\theta = 45°$.



base $6^2 + 8^2 = 10^2$; space $10^2 + 10^2 = 200$; $\tan\theta = \frac{10}{10}$

A cuboid 6 by 8 by 10 with the base diagonal 10, the space diagonal root 200 and the 45 degree angle between them marked.

> **Worked example: 1HR June 2024 Q22, adapted.** Points B, M, P in a solid box have $BM = \sqrt{200}$, $BP = \sqrt{244}$ and $MP = 10$ (each length itself found by Pythagoras in a right triangle of the box). Angle BMP needs the cosine rule on triangle BMP:

$$\cos BMP = \frac{200 + 100 - 244}{2 \times \sqrt{200} \times 10} = \frac{56}{282.8} = 0.198, \qquad \angle BMP = 78.6°$$

Order of attack: identify the target triangle, find its three sides (each possibly by its own Pythagoras), then apply the cosine or sine rule, keeping the angle you want at the centre of the notation.

Mensuration: perimeter, area, surface and volume

Metric conversions: linear cm↔m by 100, area by 100^2, **volume** by 100^3 ($1\text{ m}^3 = 10^6\text{ cm}^3$). Perimeters and areas build from triangles ($\frac{1}{2}bh$), rectangles, parallelograms (bh) and trapezia ($\frac{1}{2}(a+b)h$); the circle has circumference $2\pi r$ and area πr^2 (semicircles included). Composite shapes split into these parts.

> **Worked example: 2HR June 2024 Q10, adapted.** Hexagon $ABCDEF$ has $AB \parallel FC \parallel ED$ with $AB = 11$, $ED = FC = 23$, the perpendicular distance between FC and ED equal to 4.7 (cm) and the slant side $BC = 5$ making 30° with FC. The strip between FC and ED is a rectangle; above it the height of the trapezium $ABCF$ is $5\sin 30° = 2.5$. Split: rectangle $23 \times 4.7 = 108.1$ plus trapezium $\frac{1}{2}(11 + 23) \times 2.5 = 42.5$, so the area is 150.6 cm^2 (exact $\frac{753}{5}$). Draw the split lines before computing.

Higher adds **sectors** : arc $= \frac{\theta}{360} \times 2\pi r$, sector area $= \frac{\theta}{360} \times \pi r^2$ – for $r = 9$, $\theta = 40°$: arc $= 2\pi \approx 6.28$, area $= 9\pi \approx 28.3$. Sector perimeter adds the two radii. Solids: prisms $V =$ cross-section $\times$ length (cuboid, cylinder $V = \pi r^2 h$, surface $2\pi r^2 + 2\pi rh$); the **cone** $V = \frac{1}{3}\pi r^2 h$ with curved surface πrl (l the slant); the **sphere** $V = \frac{4}{3}\pi r^3$, surface $4\pi r^2$. A cone $r = 3$, $h = 4$ has $l = 5$ (Pythagoras), $V = 12\pi$, curved surface 15π.

Similarity: length, area and volume ratios

Similar figures have corresponding lengths in a fixed ratio k (the **scale factor**): then areas scale by k^2 and volumes by k^3 – and conversely, an area ratio 4 : 9 means a length ratio 2 : 3. Maps and models use k directly.

> **Worked example: 2HR June 2024 Q24 family, adapted.** Solid B is similar to solid A with every length k times A's. Volumes then scale by k^3: the paper's cone-plus-hemisphere pair gives $k^3 = \frac{125}{8}$, so $k = \sqrt[3]{\frac{125}{8}} = \frac{5}{2} = 2.5$. A second pair with length ratio 4 has volume ratio $4^3 = 64$ – the larger solid holds 64 times the smaller. Set the ratio up on lengths first, then square or cube it once.

> **Worked example: area to volume.** Two similar bottles have surface areas 180 cm^2 and 405 cm^2. The smaller holds 320 cm^3. Find the volume of the larger. Go through the length scale factor:

$$k^2 = \frac{405}{180} = 2.25 \;\Rightarrow\; k = 1.5 \;\Rightarrow\; k^3 = 3.375, \qquad V = 320 \times 3.375 = 1080\text{ cm}^3.$$

The common error is to multiply the volume by the area ratio 2.25 (giving 720 cm^3).

Checklist

- Classify angles; use line, point, parallel-line and triangle angle facts, including exterior-angle and polygon sums with regular-polygon interior/exterior angles (F 4.1, 4.2).
- Identify symmetry: lines and rotational order (F 4.3).
- Use bearings, speed/distance/time, density and pressure as compound measures (F 4.4).

- Construct triangles, bisectors and perpendiculars; answer locus and scale-drawing questions (F 4.5, F 4.11 B).
- Use circle language and chord/tangent properties; Higher: cyclic quadrilaterals, centre/circumference angles, intersecting chords – every step with its standard reason (F 4.6–4.7, H 4.6–4.7; June 2024 1HR Q13).
- Pythagoras and SOH CAH TOA in 2D with elevations and depressions; obtuse ratios, sine rule, cosine rule and ½ab sin C including reversals (F 4.8, H 4.8 A–C, E).
- Solve 3D problems by extracting right triangles; cosine rule on the extracted triangle (H 4.8 D, F; June 2024 1HR Q22).
- Perimeters and areas including trapezia, circles and sectors; surface areas and volumes of prisms, cylinders, cones and spheres with unit conversions (F 4.9–4.10, H 4.9, H 4.10; June 2024 2HR Q10).
- Length : area : volume ratios $k : k^2 : k^3$, used both directions (F 4.11, H 4.11; June 2024 2HR Q24 family).

Boundary notes: bearings are three-figure; constructions are judged on visible arcs (leave them in); radians are excluded – degrees only; the ambiguous sine-rule case and 3D circle work are beyond the list. Foundation meets 4.1–4.11 Foundation rows only. Worked examples are adapted from the reviewed June 2024 Higher pair (see the meta's assessment evidence); sheet questions are original unless labelled.

Vectors and transformation geometry

Pearson Edexcel · International GCSE · Mathematics A

4MA1 topic 5 (specification Issue 2, November 2017). Foundation 5.2 is the four transformations with full descriptions; 5.1 (vectors) is Higher-only and runs from notation to resultants, magnitudes and simple geometrical proofs. On the June 2024 Higher paper the vector question (2HR Q25) is the classic A/A* finisher: a chain of points expressed in **a** and **b**, then an unknown ratio k found by writing the same vector two independent ways.

Must-know for topic 5:

Family	Formulae
column vector	$\begin{pmatrix}x\\y\end{pmatrix}$; scalar multiple $k\begin{pmatrix}x\\y\end{pmatrix}=\begin{pmatrix}kx\\ky\end{pmatrix}$
magnitude	$\left\lvert\begin{pmatrix}x\\y\end{pmatrix}\right\rvert=\sqrt{x^2+y^2}$
route rule	$\overrightarrow{AC}=\overrightarrow{AB}+\overrightarrow{BC}$; reversing: $\overrightarrow{BA}=-\overrightarrow{AB}$
transformations	reflection in $x=k$, $y=k$, $y=x$; rotation (centre, angle, direction); translation $\begin{pmatrix}a\\b\end{pmatrix}$; enlargement (centre, factor k)

Vectors: notation to resultants

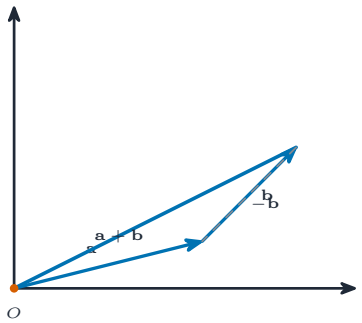
A **vector** has both magnitude and direction (a **scalar** has only size). Write it bold **a**, underlined, or as $\overrightarrow{OA}$; as a **column vector** $\begin{pmatrix}3\\-5\end{pmatrix}$ – across, then up.

Scalar multiples stretch: $2\mathbf{a}$ is twice as long and **parallel**; $-\mathbf{a}$ reverses direction; $\frac{1}{2}\mathbf{a}$ halves it.

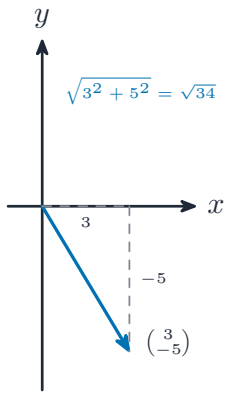
Addition is tip-to-tail: $\overrightarrow{AB}+\overrightarrow{BC}=\overrightarrow{AC}$ – the route matters, not the stops. Reverse a vector by negating: $\overrightarrow{BA}=-\overrightarrow{AB}$. The **resultant** of several legs is the single start-to-end vector: with $\overrightarrow{OA}=3\mathbf{a}$, $\overrightarrow{AB}=2\mathbf{b}$ and $\overrightarrow{BC}=2\mathbf{c}$ (the specification's own example),

$$\overrightarrow{OC}=3\mathbf{a}+2\mathbf{b}+2\mathbf{c}, \qquad \overrightarrow{CA}=-\overrightarrow{OC}+\overrightarrow{OA} \text{ summed along the route.}$$

The **modulus** (magnitude) of $\begin{pmatrix}x\\y\end{pmatrix}$ is its length by Pythagoras: $\sqrt{x^2+y^2}$, so $\left\lvert\begin{pmatrix}3\\-5\end{pmatrix}\right\rvert=\sqrt{34}\approx 5.83$. Column-vector arithmetic is componentwise: $\begin{pmatrix}2\\5\end{pmatrix}+\begin{pmatrix}-1\\3\end{pmatrix}=\begin{pmatrix}1\\8\end{pmatrix}$.

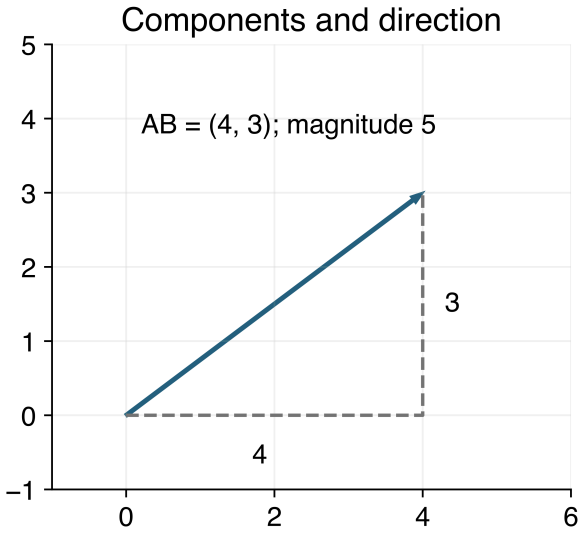


tip-to-tail: the route adds, the stops do not



modulus = length, by Pythagoras

Left: tip-to-tail addition of a and b giving the resultant, with the reversed vector shown dashed. Right: the column vector (3, -5) with its modulus root 34 marked.



AB = (4, 3) has magnitude √(4² + 3²) = 5

Vector geometry proofs

Vector proofs show parallel or half-length relations by writing the SAME vector two ways.

> **Worked example.** $OABC$ is a **parallelogram** with $\overrightarrow{OA} = \mathbf{a}$ and $\overrightarrow{OC} = \mathbf{c}$; M is the **midpoint** of diagonal OB. Prove that the **diagonals bisect** each other.

Diagonal: $\overrightarrow{OB} = \mathbf{a} + \mathbf{c}$ (route $O \to A \to B$, since $\overrightarrow{AB} = \mathbf{c}$ in a parallelogram). So $\overrightarrow{OM} = \frac{1}{2}(\mathbf{a} + \mathbf{c})$. From A: $\overrightarrow{AM} = \overrightarrow{AO} + \overrightarrow{OM} = -\mathbf{a} + \frac{1}{2}(\mathbf{a} + \mathbf{c}) = \frac{1}{2}(\mathbf{c} - \mathbf{a})$. But the other diagonal has $\overrightarrow{AC} = -\mathbf{a} + \mathbf{c} = \mathbf{c} - \mathbf{a}$, so $\overrightarrow{AM} = \frac{1}{2}\overrightarrow{AC}$: M is the midpoint of AC too. Both diagonals share the midpoint – bisected. ✓

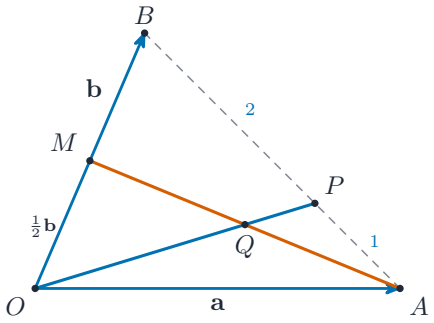
The 2HR June 2024 Q25 family asks for two things: a vector such as $\frac{8}{5}\mathbf{a} + \frac{3}{5}\mathbf{b}$ in simplest form, then an unknown k for a point on a line, found by writing one vector two independent ways and equating the **coefficients** of **a** and of **b**. Here is the method in full on an original example.

> **Worked example: finding an unknown ratio.** In triangle OAB, $\overrightarrow{OA} = \mathbf{a}$ and $\overrightarrow{OB} = \mathbf{b}$. P lies on AB with $AP : PB = 1 : 2$, and M is the midpoint of OB. The lines OP and AM meet at Q. Find $OQ : OP$.

First, $\overrightarrow{AB} = \mathbf{b} - \mathbf{a}$, so $\overrightarrow{OP} = \mathbf{a} + \frac{1}{3}(\mathbf{b} - \mathbf{a}) = \frac{2}{3}\mathbf{a} + \frac{1}{3}\mathbf{b}$. Q is on OP, so $\overrightarrow{OQ} = k\left(\frac{2}{3}\mathbf{a} + \frac{1}{3}\mathbf{b}\right)$ for some k.

Q is also on AM, where $\overrightarrow{AM} = \frac{1}{2}\mathbf{b} - \mathbf{a}$, so $\overrightarrow{OQ} = \mathbf{a} + \lambda\left(\frac{1}{2}\mathbf{b} - \mathbf{a}\right) = (1 - \lambda)\mathbf{a} + \frac{\lambda}{2}\mathbf{b}$ for some λ.

Equate the coefficients: **a**: $\frac{2}{3}k = 1 - \lambda$, and **b**: $\frac{1}{3}k = \frac{1}{2}\lambda$, so $\lambda = \frac{2}{3}k$. Then $\frac{2}{3}k = 1 - \frac{2}{3}k$, giving $k = \frac{3}{4}$ (and $\lambda = \frac{1}{2}$). So $OQ : OP = 3 : 4$, and Q is also the midpoint of AM. Never assume a point is a midpoint: give it a letter (k, λ) and equate.



write $\overrightarrow{OQ}$ along OP and along AM, then equate: $k = \frac{3}{4}$, $\lambda = \frac{1}{2}$

Q lies on both OP and AM, so $\overrightarrow{OQ}$ can be written two ways; equating the coefficients of **a** *and* **b** *gives $k = \frac{3}{4}$.*

Transformations: rotation, reflection, translation

A **rotation** needs centre, angle and direction (**anticlockwise** positive, **clockwise** negative); a **reflection** needs a **mirror line** ($x = 1$, $y = 2$, $y = x$, $y - x = 0$); a **translation** needs a distance and direction, written as the column vector $\begin{pmatrix} a \\ b \end{pmatrix}$. Rotations, reflections and translations preserve lengths and angles, so the **image** is **congruent** to the original.

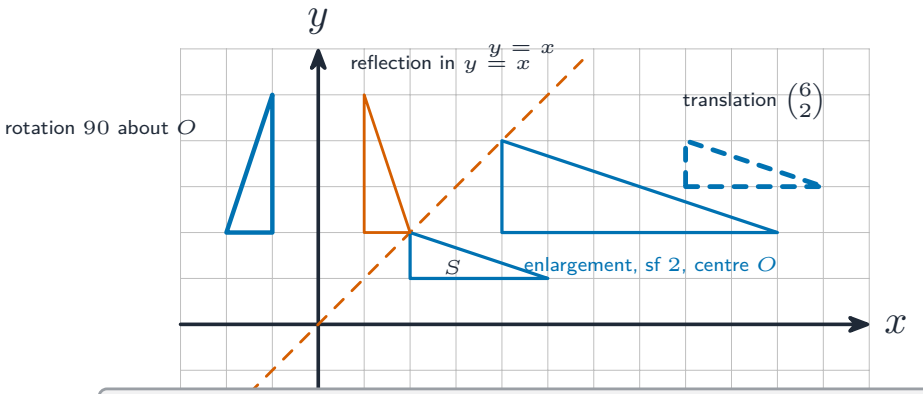
Coordinate rules for the quick cases: reflect in the x-axis: $(x, y) \to (x, -y)$; in the y-axis: $(x, y) \to (-x, y)$; in $y = x$: $(x, y) \to (y, x)$; rotate 90° anticlockwise about O: $(x, y) \to (-y, x)$; rotate 180°: $(x, y) \to (-x, -y)$; translate by $\begin{pmatrix} a \\ b \end{pmatrix}$: $(x, y) \to (x+a, y+b)$. Tracing paper does the rest – but the DESCRIPTION must name every required element.

> **Worked example: two transformations as one.** Triangle T has **vertices** $(1, 1)$, $(3, 1)$ and $(1, 2)$. Reflect T in $y = x$, then reflect the image in the x-axis. Describe the single transformation that does both.

Follow a general point: $(x, y) \to (y, x)$ in $y = x$, then $(y, x) \to (y, -x)$ in the x-axis. So $(1, 1) \to (1, -1)$, $(3, 1) \to (1, -3)$ and $(1, 2) \to (2, -1)$. The rule $(x, y) \to (y, -x)$ is a **rotation of** 90° **clockwise about** $(0, 0)$. All three parts (rotation, angle with direction, centre) are needed for full marks; "turned" or "moved" earns nothing.

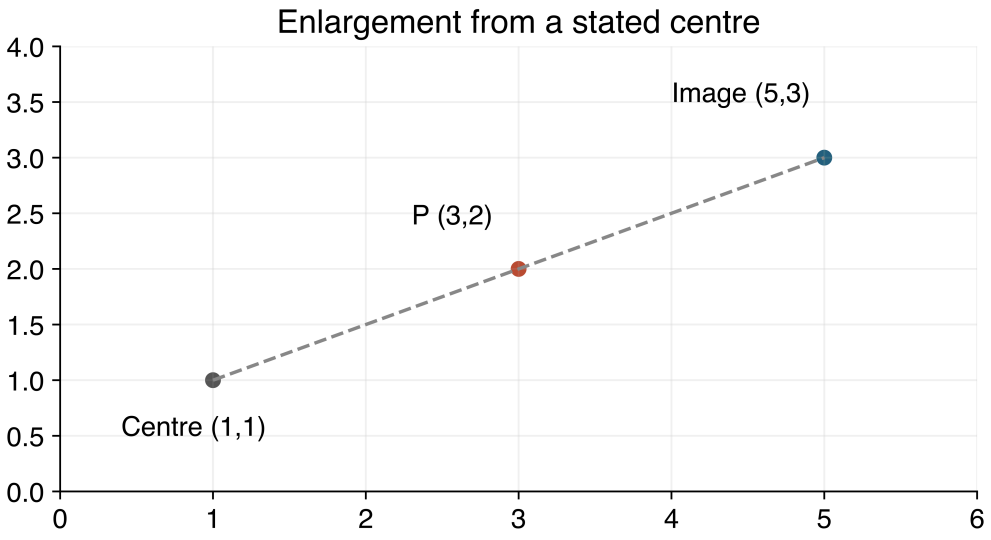
Enlargement and describing transformations

An **enlargement** is specified by a **centre of enlargement** and a positive **scale factor** (fractions included, with or without the centre marked): $(x, y) \to (kx, ky)$ about the origin. Enlargements preserve angles but NOT lengths – the image is **similar**, not congruent. A **complete description** names the transformation and every parameter: "rotation, 90° anticlockwise about $(0, 1)$"; "reflection in the line $y = x$"; "translation by $\begin{pmatrix} 3 \\ -2 \end{pmatrix}$"; "enlargement, scale factor 2, centre $(1, 1)$". Missing the centre or direction loses the mark.



a complete description names the transformation AND every parameter

A grid with a shape and its images: reflection in $y = x$, rotation 90 degrees about O, translation, and enlargement scale factor 2 - each image labelled with its full description.



Scale factor 2 from (1, 1): the image is twice as far from the centre as P

Checklist

- Use vector notation, column vectors, scalar multiples and componentwise addition/subtraction (H 5.1 A–D).
- Find resultants along a route; reverse by negating (H 5.1 F).
- Compute moduli by Pythagoras (H 5.1 E; spec example $(3, -5) \to \sqrt{34}$).
- Prove midpoint, parallel and ratio facts by writing one vector two independent ways – never assume a midpoint (H 5.1 G; June 2024 2HR Q25).
- Rotate, reflect and translate, using column vectors for translations; state congruence preservation (F 5.2 A–I).
- Enlarge with centre and scale factor (fractions included); describe any transformation completely (F 5.2 J–M).

Boundary notes: vectors at this level are in two dimensions with positive scale factors only; negative enlargement factors belong to later study. Foundation candidates meet 5.2 only. Worked examples are adapted from the reviewed June 2024 Higher paper or original (see the meta's assessment evidence); sheet questions are original unless labelled.

Statistics and probability

Pearson Edexcel · International GCSE · Mathematics A

4MA1 topic 6 (specification Issue 2, November 2017). Foundation 6.1–6.3 covers presenting data, averages with grouped estimates, and the full probability toolkit (scale, sample spaces, Venn diagrams, complements); Higher adds histograms with unequal classes, cumulative frequency work with median and interquartile range, and tree diagrams for independent and conditional events. On the June 2024 papers this strand supplied an unequal-class histogram (1HR Q16), a cumulative-frequency graph with quartile reads (2HR Q11) and the algebra-heavy without-replacement question (1HR Q21).

Must-know for topic 6:

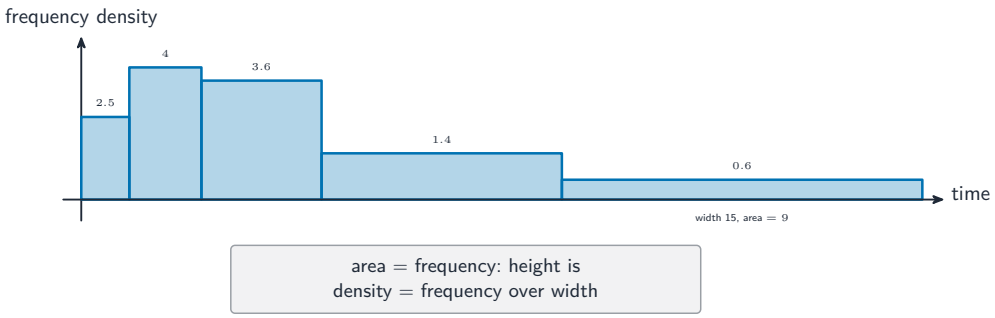
Family	Formulae
averages	mean $= \dfrac{\sum x}{n}$; grouped mean $= \dfrac{\sum fm}{\sum f}$ (m = midpoints)
histogram	frequency density $= \dfrac{\text{frequency}}{\text{class width}}$ – bar AREA is the frequency
cumulative frequency	plot at the UPPER class boundary; median at $\frac{n}{2}$, quartiles at $\frac{n}{4}$ and $\frac{3n}{4}$
probability	$P(A') = 1 - P(A)$; $P(A \cup B) = P(A) + P(B) - P(A \cap B)$; independent: multiply

Collecting and presenting data

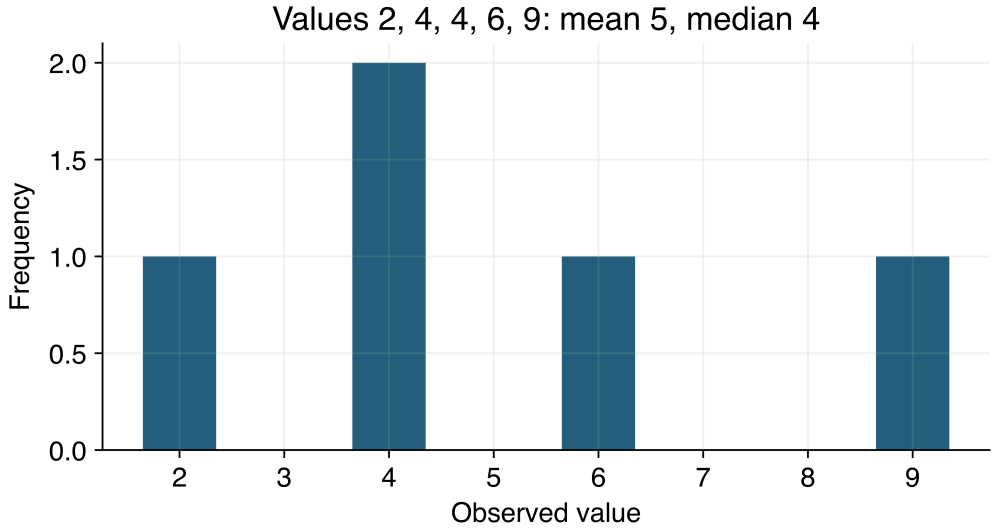
Tabulate before drawing: tally into a frequency table, keep class boundaries explicit, then choose the diagram – bar chart (discrete categories), pie chart (proportions), pictogram, or a frequency polygon for grouped data. Interpretation runs both ways: read values off a given chart and compare distributions (two groups on the same axes; a truncated axis that misleads is also fair comment).

Higher draws **histograms** with **unequal class widths**: the bar's height is the **frequency density** $= \dfrac{\text{frequency}}{\text{class width}}$, so the AREA represents the frequency. Equal-width classes are the special case where height alone works.

> **Worked example: 1HR June 2024 Q16, adapted.** Classes of widths 2, 3, 5, 10, 15 hold frequencies 5, 12, 18, 14, 9. Densities: $\frac{5}{2} = 2.5$, $\frac{12}{3} = 4$, $\frac{18}{5} = 3.6$, $\frac{14}{10} = 1.4$, $\frac{9}{15} = 0.6$ – the paper's marking accepts bars of correct width whose heights are in this ratio. Check yourself: the last bar looks tall only because its width is 15; its area is $0.6 \times 15 = 9$. ✓



A histogram with unequal class widths 2, 3, 5, 10, 15, frequencies 5, 12, 18, 14, 9 and heights marked as the frequency densities 2.5, 4, 3.6, 1.4, 0.6, with the area-is-frequency takeaway.



For 2, 4, 4, 6, 9: mean = 25 ÷ 5 = 5, median = 4

Averages and spread

The **mean** sums and divides; the **median** orders and takes the middle; the **mode** is the most frequent. For 3, 7, 8, 10, 12: mean 8, median 8, range $12 - 3 = 9$. For grouped data, estimate the mean with midpoints: multiply each midpoint by its frequency, sum, divide by the total; state the **modal class** (the class with the highest frequency density when widths differ).

Worked example: grouped mean. Times t (minutes) for 25 students:

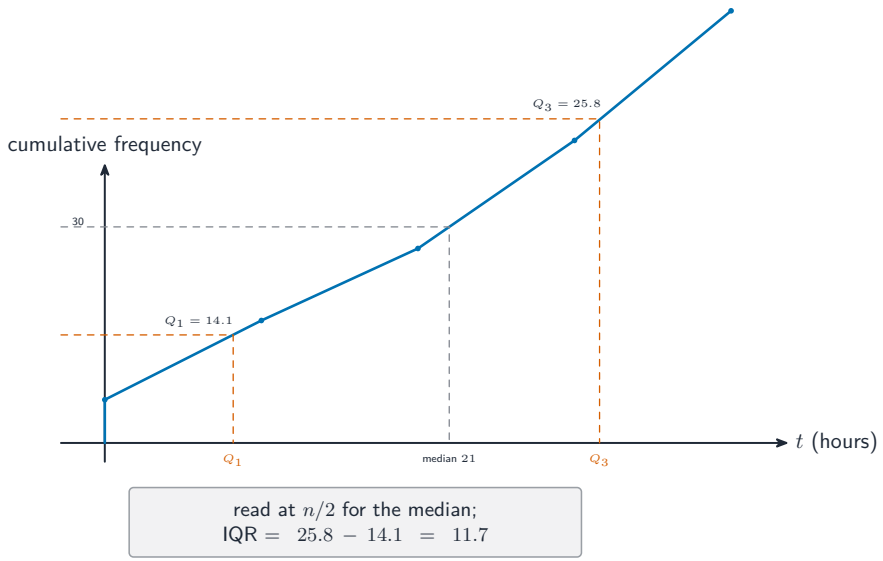
Time	$0 < t \leq 10$	$10 < t \leq 20$	$20 < t \leq 30$	$30 < t \leq 40$
Frequency f	4	7	9	5
Midpoint m	5	15	25	35

$\sum fm = 20+105+225+175 = 525$ and $\sum f = 25$, so the mean is about $525 \div 25 = 21$ minutes. It is only an **estimate**, because each student is treated as if at the midpoint. The modal class is $20 < t \leq 30$. Dividing by 4 (the number of classes) instead of 25 is the usual slip.

Higher quantifies **spread** with the **quartiles**: order the data, take the median, then the medians of the lower and upper halves give Q_1 and Q_3; the **interquartile range** is $Q_3 - Q_1$ (resistant to outliers, unlike the range). For 4, 6, 7, 9, 10, 12, 14, 15: the median is 9.5, the lower half 4, 6, 7, 9 gives $Q_1 = 6.5$, the upper half 10, 12, 14, 15 gives $Q_3 = 13$, so the IQR is $13 - 6.5 = 6.5$.

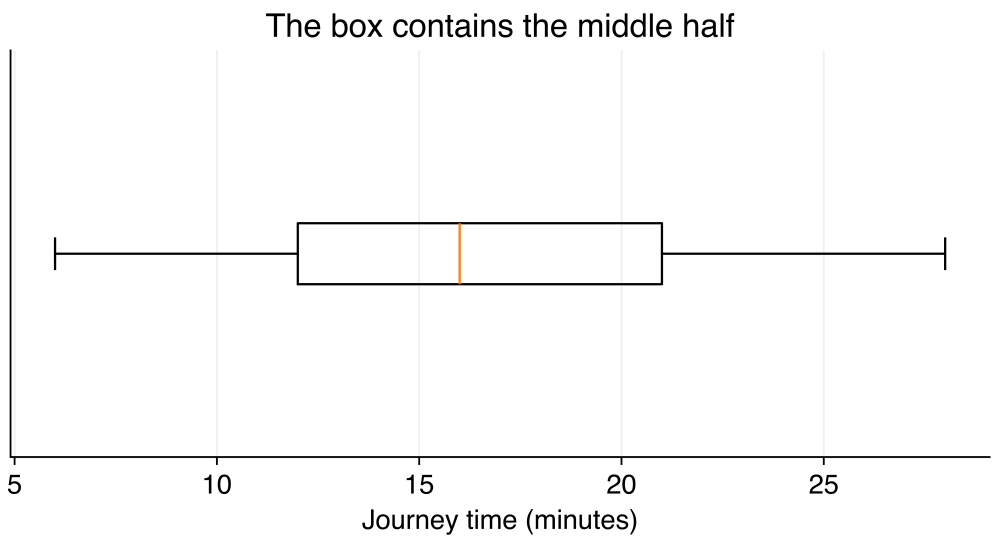
Cumulative frequency diagrams

A **cumulative frequency** table adds frequencies as classes pass; plot each total against its UPPER class boundary and join with a smooth increasing curve – the **ogive**. Reads: the median is the value at $\frac{n}{2}$ on the curve; the quartiles at $\frac{n}{4}$ and $\frac{3n}{4}$; the IQR is their difference; percentiles work the same way, and "how many above X" reads the total at X and subtracts from n.



The cumulative frequency curve for 60 workers: points (10, 6), (15, 17), (20, 27), (25, 42), (30, 60), with the median 21 and quartiles 14.1 and 25.8 marked and the IQR 11.7 stated.

Worked example: 2HR June 2024 Q11 family, adapted. 60 workers' homework times (hours per week): cumulative frequencies 6, 17, 27, 42, 60 at upper boundaries 10, 15, 20, 25, 30. The median sits at the 30th worker: between 20 (27 workers) and 25 (42), so $20 + 5 \times \frac{30-27}{42-27} = 21$ hours. The quartiles: the 15th worker gives $Q_1 = 10 + 5 \times \frac{15-6}{17-6} = 14.1$; the 45th gives $Q_3 = 25 + 5 \times \frac{45-42}{60-42} = 25.8$; IQR ≈ 11.7. Draw the reading lines on the graph – the marks are for the reads, not just the answers.

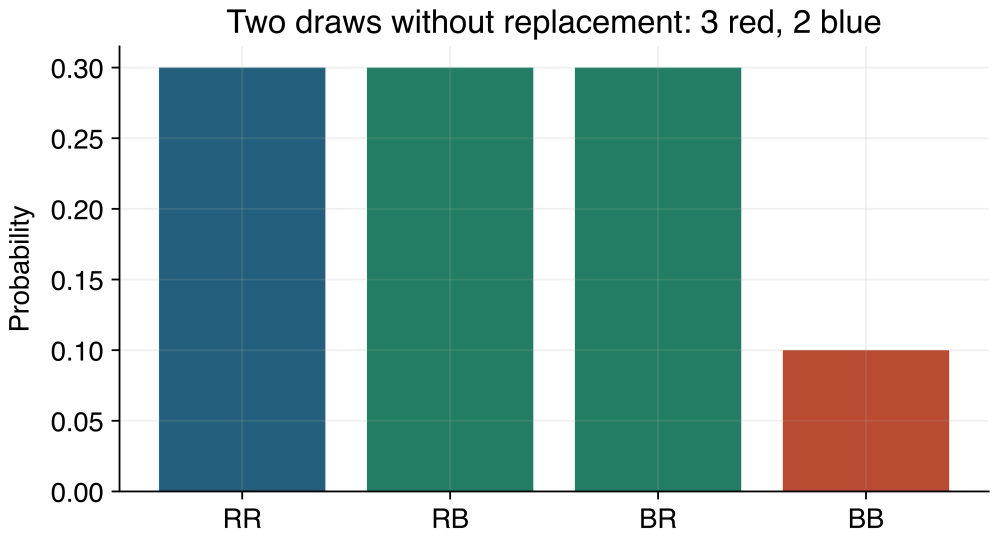


The box holds the middle half: quartiles 12 and 21 minutes, IQR 9, median 16

Probability foundations

Probability measures likelihood on the scale 0 (impossible) to 1 (certain). A theoretical model counts equally likely outcomes; an experiment estimates from frequency: $P(\text{event}) \approx \frac{\text{times it happened}}{\text{trials}}$ (estimates from previously collected data included). The **sample space** lists all outcomes – for two successive events, a grid or systematic list; an event's probability counts the favourable cells. The **complement** rule: $P(A') = 1 - P(A)$ – often the fast route ("at least one" questions).

Venn diagrams : regions for each set and the overlap; probabilities fill the regions and sum to 1, with $P(A \cup B) = P(A) + P(B) - P(A \cap B)$. Example: 30 students, 18 like cricket (C), 15 tennis (T), 7 both: $P(C \cup T) = \frac{18+15-7}{30} = \frac{26}{30}$, and $P(\text{neither}) = 1 - \frac{26}{30} = \frac{2}{15}$.



Without replacement: P(RR) = 3/5 × 2/4 = 0.3, P(BB) = 2/5 × 1/4 = 0.1

Tree diagrams and combined events

Tree diagrams multiply along branches and add between outcomes. WITH replacement, branches repeat – the events are **independent** : $P(A \cap B) = P(A) \times P(B)$. WITHOUT replacement, the second branch's denominator drops by one and its numerator by the first outcome: the draws are dependent, and the working shows the changing fractions.

Worked example: 1HR June 2024 Q21 family, adapted. A bag holds 5 red, 6 blue and 9 green sweets; two are taken without replacement. $P(\text{one red and one blue, in either order}) = \frac{5}{20} \times \frac{6}{19} + \frac{6}{20} \times \frac{5}{19} = \frac{60}{380} = \frac{3}{19}$. The paper's version runs the same machinery with an unknown x and solves the resulting quadratic (its verified results: $x = 11$, final probability $\frac{7}{75}$): set the two-route expression equal to the given probability, expand, solve, and reject the root the context forbids.

Worked example: an unknown total. A bag holds n sweets, of which 6 are orange. Two are taken without replacement, and $P(\text{both orange}) = \frac{1}{3}$. Find n.

$$\frac{6}{n} \times \frac{5}{n-1} = \frac{1}{3} \Rightarrow 90 = n(n-1) \Rightarrow n^2 - n - 90 = 0 \Rightarrow (n-10)(n+9) = 0.$$

A number of sweets cannot be negative, so $n = 10$. Check: $\frac{6}{10} \times \frac{5}{9} = \frac{30}{90} = \frac{1}{3}$. ✓

Conditional probability shrinks the world: $P(B \mid A) = \dfrac{P(A \cap B)}{P(A)}$ – on a

tree, the second branch given the first happened. With the bag above, $P(\text{blue second} \mid \text{red first}) = \frac{6}{19}$ read straight off the branch.

Checklist

- Tabulate and present data; interpret charts and compare distributions (F 6.1 A–C).
- Draw histograms with unequal widths via frequency density; area is the frequency (H 6.1 A; June 2024 1HR Q16).
- Mean, median, mode, range; grouped mean via midpoints; modal class (F 6.2 B–D).
- Quartiles and IQR for discrete data by position (H 6.2 B–C).
- Construct cumulative frequency curves from tables; read medians, quartiles, IQR and percentiles with drawn reading lines (H 6.1 B–C, H 6.2 A, D; June 2024 2HR Q11).
- Probability scale; theoretical vs experimental estimates; sample spaces and systematic listing for two events; Venn diagrams with the addition rule; complements (F 6.3 A–H).
- Tree diagrams: multiply along, add between; with replacement (independent) vs without; conditional probability read from branches; algebraic setups ending in quadratics (H 6.3 A–D; June 2024 1HR Q21 family).

Boundary notes: histograms use frequency density (not frequency) whenever widths differ; quartile conventions here are positional (medians of the lower and upper halves); expected value and formal set notation belong to later study. Foundation candidates meet 6.1–6.3 Foundation rows only. Worked examples are adapted from the reviewed June 2024 papers or original; sheet questions are original unless labelled.