A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 1 · ~9 MIN READ

Physical quantities and units

SI base units and derived units, checking equations for homogeneity, prefixes, estimates, systematic and random errors, precision and accuracy, combining uncertainties, and scalars and vectors.

SI base units | Derived units | Homogeneity | Prefixes | Estimates | Systematic & random errors | Precision & accuracy | Uncertainties

RS by Riyaz Sir
mentorriyaz.in

Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Every physical quantity is a number × a unit.** The five SI base units in this syllabus are kg, m, s, A and K. Every other unit can be written as a product or quotient of these.
- **An equation is homogeneous** when every term has the same base units. Homogeneity is necessary but not sufficient: a homogeneous equation can still be wrong (it can't check pure numbers like ½).
- **Random errors** scatter readings both ways and are reduced by repeating. **Systematic errors** shift every reading the same way (e.g. a zero error) and are not reduced by repeating.
- **Uncertainties:** add absolute uncertainties for sums and differences; add percentage uncertainties for products and quotients; multiply by the power for powers.
- **Vectors** have magnitude and direction. Add them tip-to-tail; resolve them into perpendicular components F cos θ and F sin θ.

BY THE END YOU CAN

- Express derived units in SI base units and check equations for homogeneity.
- Use prefixes from pico to tera and make sensible estimates.
- Distinguish systematic from random errors, and precision from accuracy.
- Combine uncertainties in derived quantities.
- Add, subtract and resolve coplanar vectors.

1 SI units

Base and derived units

Base quantity	SI unit	Symbol
mass	kilogram	kg
length	metre	m
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance (A Level)	mole	mol

- **Derived units** come from the defining equation. Force: F = ma, so N = kg m s^{-2}. Energy: W = Fs, so J = kg m^2 s^{-2}. Power: W s^{-1} = kg m^2 s^{-3}. Charge: Q = It, so C = A s. Potential difference: V = W/Q, so V = kg m^2 s^{-3} A^{-1}.

WORKED EXAMPLE

Express the ohm in SI base units.

1. R = V/I and V = W/Q = W/(It) M1
2. V = kg m^2 s^{-2} / (A s) = kg m^2 s^{-3} A^{-1} A1
3. **Ω = V/A = kg m^2 s^{-3} A^{-2}** A1

WORKED EXAMPLE

The drag force on a sphere is $F = C\rho v^2 A$, where ρ is density, v speed and A area. Find the base units of C.

1. C = F/(ρv^2A) M1
2. units: kg m s^{-2} / (kg m^{-3} × m^2 s^{-2} × m^2) M1
3. **= kg m s^{-2} / (kg m s^{-2}) ⇒ C has no units** A1

COMMON MISTAKE

Giving a unit for a constant without checking. In 2024, many candidates wrote the units of a drag constant wrongly by not cancelling carefully. Write every quantity's units, then cancel one base unit at a time.

Riyaz Sir

Homogeneity

- **Test:** reduce each term to base units. If any term differs, the equation is wrong.
- **Limitation:** a homogeneous equation can still be wrong, because base units can't show numerical factors (½, 2π) or a wrong sign.

WORKED EXAMPLE

Show that $s = ut + \frac{1}{2}at^2$ is homogeneous.

1. s: m
2. ut: m s^{-1} × s = m
3. at^2: m s^{-2} × s^2 = m **M1**
4. **every term is in m, so the equation is homogeneous (the ½ is not tested) A1**

Prefixes and estimates

Prefix	pico	nano	micro	milli	centi	deci	kilo	mega	giga	tera
Symbol	p	n	μ	m	c	d	k	M	G	T
Power	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^{3}	10^{6}	10^{9}	10^{12}

- **Squared and cubed prefixes:** 1 mm^2 = $(10^{-3}\ m)^2$ = $10^{-6}\ m^2$; 1 cm^3 = $10^{-6}\ m^3$. The 2024 Paper 2 report flagged mm^2 → m^2 conversions.
- **Estimates to know:** mass of an adult ≈ 70 kg; height of a room ≈ 3 m; walking speed ≈ 1.5 m s^{-1}; mass of an apple ≈ 0.1 kg; power of a kettle ≈ 2 kW; wavelength of visible light ≈ 5 × 10^{-7} m; diameter of an atom ≈ 10^{-10} m; mass of a car ≈ 1000 kg.

COMMON MISTAKE

Confusing tera (10^{12}) and giga (10^{9}), or milli (10^{-3}) and micro (10^{-6}). The 2024 reports list both.

2 Errors and uncertainties

Systematic and random errors

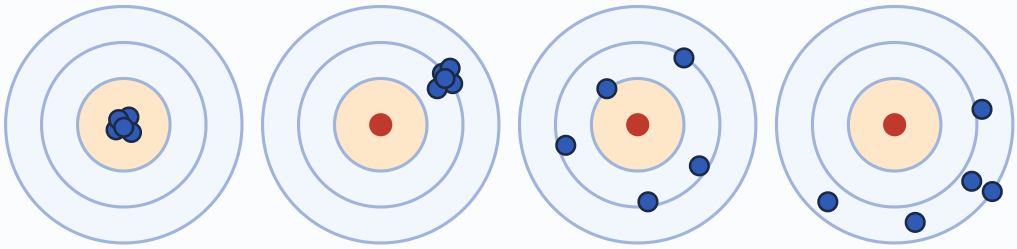
Systematic error — an error that shifts every reading by the same amount or in the same direction, e.g. a zero error on a meter or a ruler read from the wrong end. Repeating does not reduce it; it is removed by correcting or recalibrating.

Random error — an error that makes readings scatter unpredictably above and below the true value, e.g. reaction time when using a stopwatch. It is reduced by repeating and averaging, or by plotting a graph.

Precision — how close repeated readings are to each other (a small spread). Also used for the smallest division of an instrument.

Accuracy — how close a measurement is to the true value.

Red centre = true value. Blue dots = repeated readings.



accurate and precise | **precise not accurate** | **accurate on average not precise** | **neither**

Precise = small spread (small random error).
Accurate = close to the true value (small systematic error).

Precision is about spread; accuracy is about the centre.

Combining uncertainties

Result	Rule	Example
y = a + b or a − b	add **absolute** uncertainties	Δy = Δa + Δb
y = ab or a/b	add **fractional** (or %) uncertainties	Δy/y = Δa/a + Δb/b
$y = a^n$	multiply the fractional uncertainty by |n|	Δy/y = |n| Δa/a
y = ka (k exact)	same fractional uncertainty	Δy/y = Δa/a

- **A difference can have a large % uncertainty.** If T_1 = 20.0 ± 0.5 °C and T_2 = 25.0 ± 0.5 °C, the rise is 5.0 ± 1.0 °C: 20%. In 2024, Paper 1 candidates forgot to add both uncertainties for a temperature difference.

WORKED EXAMPLE

The resistivity of a wire is ρ = RA/L with A = πd²/4. R = 4.20 ± 0.05 Ω, d = 0.50 ± 0.01 mm and L = 1.000 ± 0.002 m. Find the percentage uncertainty in ρ.

1. %R = 0.05/4.20 × 100 = 1.19% C1
2. %d = 0.01/0.50 × 100 = 2.0%, so %(d²) = 4.0% C1
3. %L = 0.2% C1
4. **%ρ = 1.19 + 4.0 + 0.2 = 5.4%** A1

COMMON MISTAKE

Multiplying percentage uncertainties, or adding an absolute to a percentage. Both appeared in 2024 (e.g. 3 + 2 × 5 = 13% from mixed forms). Convert everything to % first, then add.

EXAM TIP

Uncertainty to 1 or 2 significant figures, and the value to the same decimal place: 1.27 ± 0.07 m, not 1.2734 ± 0.07 m.

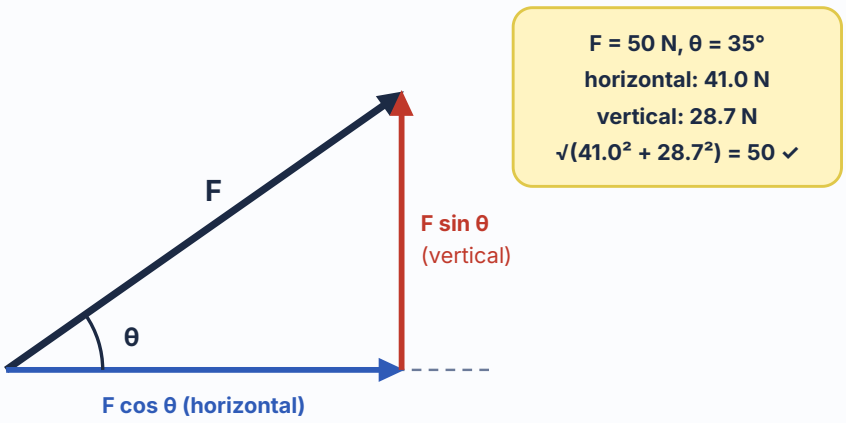
3 Scalars and vectors

Adding and resolving

Scalar — a quantity with magnitude only: mass, distance, speed, time, energy, power, temperature, charge.

Vector — a quantity with magnitude and direction: displacement, velocity, acceleration, force, momentum, weight, electric field strength.

- **Adding two vectors:** draw them tip-to-tail; the resultant goes from the start of the first to the end of the second. Perpendicular vectors: use Pythagoras and tan.
- **Subtracting:** a − b = a + (−b). **Change in velocity** Δv = v − u is a vector subtraction. A ball hitting a wall at 15 m s^{-1} and rebounding at 20 m s^{-1} has Δv = 35 m s^{-1}, not 5 m s^{-1}.



The two perpendicular components together have the same effect as F.

Resolving a 50 N force at 35° to the horizontal.

WORKED EXAMPLE

A boat heads due north at 4.0 m s^{-1} across a river flowing east at 3.0 m s^{-1}. Find the resultant velocity.

1. magnitude = √(4.0² + 3.0²) = **5.0 m s^{-1}** C1 A1
2. **angle east of north = $\tan^{-1}(3.0/4.0)$ = 37°** A1

COMMON MISTAKE

Treating a change in velocity as a difference of speeds. The 2024 Paper 1 report: many took 20 − 15 instead of 20 − (−15). Choose a positive direction and keep signs.

LINKING QUESTION

Uncertainties come back in every practical: see Kinematics for the free-fall experiment and Deformation of solids for the Young modulus; vectors are used for forces in Forces, density and pressure.

Test yourself — cover the answers first

QUICK CHECK

1. Write the newton in SI base units.

2. Express 3.5 μA in amperes.
3. Which type of error is reduced by repeating readings?
4. A length is 12.0 ± 0.1 cm. What is the percentage uncertainty in its cube?
5. Is kinetic energy a scalar or a vector?

EXAM-STYLE

6. The speed v of a wave on a string is thought to be $v = \sqrt{(T/\mu)}$, where T is tension and μ is mass per unit length. Show that the equation is homogeneous.
7. The period of a pendulum is $T = 2\pi\sqrt{(l/g)}$. l = 0.800 ± 0.002 m and T = 1.80 ± 0.02 s. Calculate g and its absolute uncertainty.
8. State one systematic error and one random error when timing a falling object with a hand-held stopwatch.

Show answers

1. kg m s^{-2}
2. 3.5×10^{-6} A
3. random error
4. 3 × 0.83% = 2.5%
5. scalar
6. T/μ: kg m s^{-2} / (kg m^{-1}) = m^2 s^{-2}; square root gives m s^{-1}, the units of v
7. $g = 4\pi^2 l/T^2 = 9.75$ m s^{-2}; %g = 0.25% + 2 × 1.1% = 2.5%; g = 9.7 ± 0.2 m s^{-2}
8. systematic: reaction-time delay at start and stop (consistent bias), or a stopwatch zero error; random: variation in reaction time between attempts

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Share with a friend

Ask Riyaz Sir

Want regular help? Send this to your parent →