

Physical quantities and units

A-Level Physics 9702 · Topic 1 revision notes · AS

The language of the subject: SI units, homogeneity, estimates, errors and uncertainties, and adding and resolving vectors. 16 definitions to learn word for word, 12 equations in their own column, 6 diagrams and graphs. Read it, cover it, test yourself.

- 1.1 Physical quantities
- 1.2 SI units
- 1.3 Errors and uncertainties
- 1.4 Scalars and vectors

Definitions (mark-scheme wording) Equations Exam traps

1.1 Physical quantities

Definitions

Physical quantity: a quantity that can be measured, stated as a numerical magnitude and a unit.

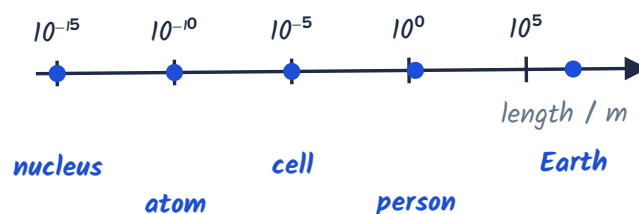
Estimate: an approximate value, found by reasoning, correct to the nearest order of magnitude.

Order of magnitude: the power of ten nearest to the value of a quantity.

Key points

- ✓ Every quantity = **number × unit**; a bare number answers no physics question.
- ✓ Useful estimates: adult mass $\sim 70 \text{ kg}$, walking speed $\sim 1.5 \text{ m s}^{-1}$, door height $\sim 2 \text{ m}$.
- ✓ More: atom $\sim 10^{-10} \text{ m}$, nucleus $\sim 10^{-15} \text{ m}$, room air mass $\sim 50 \text{ kg}$, domestic lamp $\sim 10\text{--}60 \text{ W}$.
- ✓ Give estimates to **1 significant figure**; the power of ten is what matters.
- ✓ Check every final answer for a sensible size before moving on.

1 sig. fig. + the right power of ten



Orders of magnitude of length: each step on the scale is a factor of 10^5 .

Watch out!

- ! An answer wrong by several powers of ten (a runner at 10^6 m s^{-1}) signals a unit or prefix slip.
- ! Quoting an estimate to 4 significant figures implies precision you do not have.

1.2 SI units

Definitions

SI base quantities: mass (kg), length (m), time (s), electric current (A), thermodynamic temperature (K) and amount of substance (mol).

Derived unit: a unit formed by multiplying and/or dividing base units.

Homogeneous equation: an equation in which every term has the same base units.

Key points

- ✓ Syllabus base units to recall: **kg, m, s, A, K** (and mol).
- ✓ Express derived units in base units via a defining equation: $N = \text{kg m s}^{-2}$ from $F = ma$.
- ✓ $J = N \text{ m} = \text{kg m}^2 \text{ s}^{-2}$; $W = J \text{ s}^{-1} = \text{kg m}^2 \text{ s}^{-3}$; $\text{Pa} = N \text{ m}^{-2} = \text{kg m}^{-1} \text{ s}^{-2}$.
- ✓ $C = A \text{ s}$; $V = W A^{-1} = \text{kg m}^2 \text{ s}^{-3} A^{-1}$.
- ✓ Homogeneity check: reduce each term to base units; they must all match.
- ✓ A homogeneous equation can still be wrong: **pure numbers** ($\frac{1}{2}$, 2π) carry no units.
- ✓ Prefixes: p 10^{-12} , n 10^{-9} , μ 10^{-6} , m 10^{-3} , c 10^{-2} , d 10^{-1} , k 10^3 , M 10^6 , G 10^9 , T 10^{12} .

Equations

$$F = ma$$

newton in base units: kg m s^{-2}
N

$$W = Fs$$

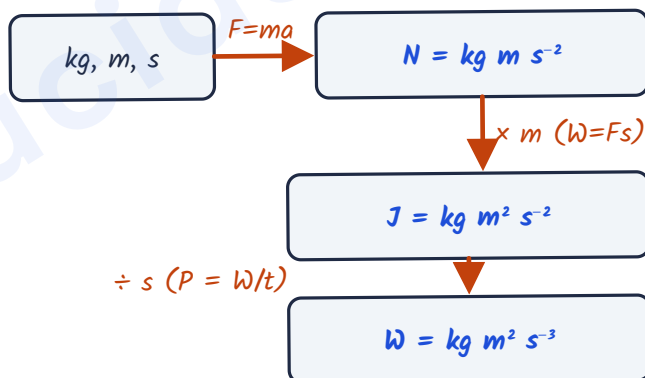
joule in base units: $\text{kg m}^2 \text{ s}^{-2}$
J

$$P = W / t$$

watt in base units: $\text{kg m}^2 \text{ s}^{-3}$
W

$$Q = It$$

coulomb in base units: $A \text{ s}$
C



Building a derived unit: follow the defining equations back to base units.

Watch out!

- ! Temperature base unit is the **kelvin**, not $^{\circ}\text{C}$; charge is **not** a base quantity (current is).
- ! Writing the mass base unit as g instead of **kg**.
- ! Prefix powers: $1 \text{ cm}^2 = 10^{-4} \text{ m}^2$ and $1 \text{ cm}^3 = 10^{-6} \text{ m}^3$, not 10^{-2} .

1.3 Errors and uncertainties

Definitions

Systematic error: an error that shifts every reading by the same amount or in the same direction (e.g. a zero error); not reduced by repeating.

Random error: an error that causes readings to scatter unpredictably about the mean; reduced by repeating and averaging.

Precision: how close repeated measurements are to each other (small spread).

Accuracy: how close a measurement (or the mean) is to the true value.

Absolute uncertainty: the range within which the true value is expected to lie, $\pm \Delta x$, in the unit of the quantity.

Fractional / percentage uncertainty: $\Delta x / x$ (or $\times 100\%$).

Equations

$$y = a \pm b; \Delta y = \Delta a + \Delta b$$

sum or difference: add absolute uncertainties
unit of y

$$y = ab \text{ or } a/b; \Delta y/y = \Delta a/a + \Delta b/b$$

product or quotient: add fractional uncertainties
no unit

$$y = a^n; \Delta y/y = n \Delta a/a$$

power: multiply fractional uncertainty by n
no unit

$$\% \text{ unc.} = (\Delta x / x) \times 100$$

percentage uncertainty
%

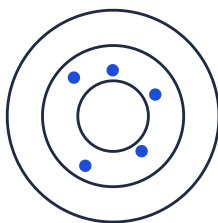
Key points

- ✓ Systematic errors: **zero error**, wrongly calibrated scale, parallax always from one side, reaction time.
- ✓ Systematic error shows as a straight-line graph that **misses the origin** when it should pass through it.
- ✓ Random errors: fluctuating readings, reaction time varying, judging a swing or a meniscus.
- ✓ Uncertainty of a mean: **half the range** of the repeats.
- ✓ Adding or subtracting: **add absolute uncertainties**.
- ✓ Multiplying or dividing: **add fractional (percentage) uncertainties**.
- ✓ Power n: **multiply** the fractional uncertainty by |n|. Constants (π , 2) add no uncertainty.
- ✓ Give the final uncertainty to 1 (or 2) sig. figs; round the value to the same decimal place.

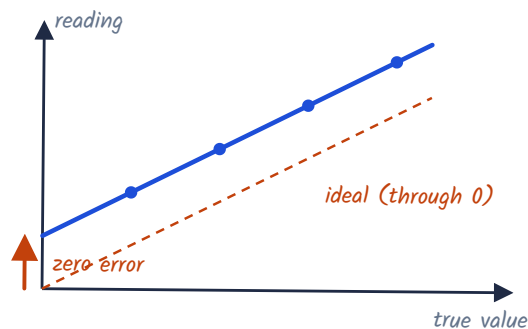
precise,
not accurate



accurate,
not precise



Precise but not accurate (systematic shift) versus accurate but not precise (random scatter).



Zero error: a systematic error shifts every point equally, so the line has the right gradient but misses the origin.

Watch out!

- ! Repeating reduces **random** error only; a systematic error must be found and corrected.
- ! Subtracting two close values: the absolute uncertainties **add**, so the percentage uncertainty can become huge.
- ! For r in $V = (4/3)\pi r^3$: % uncertainty in V is **3 ×** that in r .

1.4 Scalars and vectors

Definitions

Scalar: a quantity that has magnitude only.

Vector: a quantity that has both magnitude and direction.

Resultant: the single vector that has the same effect as two or more vectors combined.

Resolving: splitting a vector into two perpendicular components.

Key points

- ✓ **Scalars:** distance, speed, mass, time, energy, power, temperature, charge.
- ✓ **Vectors:** displacement, velocity, acceleration, force, weight, momentum, field strength.
- ✓ Add vectors **tip-to-tail**; the resultant runs from the first tail to the last tip.
- ✓ Scale drawing: draw to scale, measure the resultant length and angle.
- ✓ Perpendicular vectors: **Pythagoras** for magnitude, **tan** for direction.
- ✓ Subtracting a vector = adding it **reversed** (e.g. change in velocity $\Delta v = v - u$).
- ✓ Components along perpendicular axes can be treated **independently**.

Equations

$$F_x = F \cos \theta$$

component along the axis the angle is measured from
N

$$F_y = F \sin \theta$$

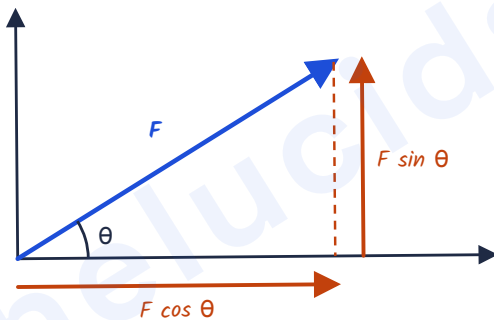
perpendicular component
N

$$R = \sqrt{F_x^2 + F_y^2}$$

magnitude of the resultant
N

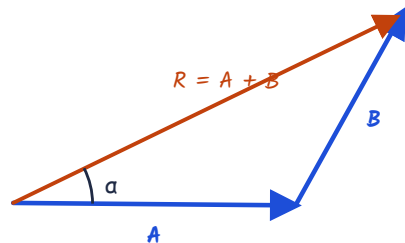
$$\tan \theta = F_y / F_x$$

direction of the resultant
-



Resolving: $\cos \theta$ goes with the axis the angle touches, $\sin \theta$ with the other.

tail of A to tip of B



Adding vectors tip-to-tail: the resultant R closes the triangle.

Watch out!

- ! If θ is measured from the **vertical**, the vertical component is $F \cos \theta$.
- ! Adding magnitudes of non-parallel vectors: 3 N + 4 N at right angles is **5 N**, not 7 N.