

AS & A Level · Physics (9702) · Chapter 1

Physical Quantities, Units and Vectors



Syllabus topic 1: 1.1 Physical quantities · 1.2 SI units · 1.3 Errors and uncertainties · 1.4

Scalars and vectors

For the Cambridge International AS & A Level Physics 9702 syllabus, exams in 2025, 2026 and 2027 (AS Level content)

Syllabus statements covered in this chapter

Syllabus ref.	What you must be able to do	Level
1.1 statements 1-2	Every physical quantity is a numerical magnitude and a unit; make reasonable estimates of physical quantities	AS
1.2 statements 1-4	The five SI base quantities and units; derived units as products or quotients of base units; checking homogeneity of equations; the prefixes pico to tera	AS
1.3 statements 1-3	Systematic errors (including zero errors) and random errors; precision and accuracy; uncertainty in a derived quantity by adding absolute or percentage uncertainties	AS
1.4 statements 1-3	Scalars and vectors; adding and subtracting coplanar vectors; resolving a vector into two perpendicular components	AS

What is inside

1. Concept notes, 8 worked examples
2. Practical skills (Paper 3); common mistakes from examiner reports
3. 20 MCQs (Paper 1 style), explained
4. 3 structured questions (Paper 2 style) with full mark schemes
5. Quick-reference sheet, "I can" checklist

How to read these notes

AS = AS Level content (Papers 1, 2 and 3)

A = A Level only (Papers 4 and 5)

red = key term green = definition

1 = one mark in the mark scheme

★ **Exam tip:** Units are written in index form, as on the papers: m s^{-2} , kg m^{-1} . Use $g = 9.81 \text{ m s}^{-2}$ (from the data sheet).

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1.1 Physical quantities

- A **physical quantity** is a **numerical magnitude together with a unit**, e.g. 2.5 kg. A number without its unit is meaningless (except for a ratio such as refractive index or strain).
- Be able to **estimate** everyday values to the right power of ten:

Quantity	Estimate	Quantity	Estimate
mass of an adult	70 kg	height of a room	3 m
mass of an apple	0.1 kg	diameter of an atom	10^{-10} m
walking speed	1.5 m s^{-1}	power of a kettle	2 kW
speed of a car on a motorway	30 m s^{-1}	density of water	1000 kg m^{-3}
weight of a 1 kg bag	10 N	atmospheric pressure	$1 \times 10^5 \text{ Pa}$

1.2 SI units

The five SI base quantities (learn these): mass – **kg**; length – **m**; time – **s**; current – **A**; temperature – **K**.

- Every other unit is a **derived unit**: a product or quotient of base units, found from the defining equation.

Quantity	Defining equation	Unit	Base units
force	$F = ma$	N	kg m s^{-2}
work, energy	$W = Fs$	J	$\text{kg m}^2 \text{s}^{-2}$
power	$P = W/t$	W	$\text{kg m}^2 \text{s}^{-3}$
pressure	$p = F/A$	Pa	$\text{kg m}^{-1} \text{s}^{-2}$
charge	$Q = It$	C	A s
potential difference	$V = W/Q$	V	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-1}$
resistance	$R = V/I$	Ω	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-2}$
frequency	$f = 1/T$	Hz	s^{-1}

- An equation is **homogeneous** if **every term has the same base units**. A homogeneous equation may still be wrong (a missing number such as $\frac{1}{2}$ has no units), but a non-homogeneous one is certainly wrong.
- Prefixes**: pico p 10^{-12} , nano n 10^{-9} , micro μ 10^{-6} , milli m 10^{-3} , centi c 10^{-2} , deci d 10^{-1} , kilo k 10^3 , mega M 10^6 , giga G 10^9 , tera T 10^{12} . Watch squares and cubes: $1 \text{ mm}^2 = 10^{-6} \text{ m}^2$, $1 \text{ cm}^3 = 10^{-6} \text{ m}^3$.

Worked example 1: base units of power

$$P = \frac{W}{t} = \frac{Fs}{t}: \text{units of force} \times \text{distance} \div \text{time} = (\text{kg m s}^{-2})(\text{m})(\text{s}^{-1}) = \text{kg m}^2 \text{s}^{-3}.$$

Worked example 2: homogeneity

Show that $v^2 = u^2 + 2as$ is homogeneous.

v^2 and u^2 : $(\text{m s}^{-1})^2 = \text{m}^2 \text{s}^{-2}$. $2as$: $(\text{m s}^{-2})(\text{m}) = \text{m}^2 \text{s}^{-2}$ (2 has no unit). Every term is **$\text{m}^2 \text{s}^{-2}$** , so the equation is homogeneous.

Worked example 3: units of a constant

The drag force on a ball is $F = kv^2$. Find the base units of k .

$$k = \frac{F}{v^2}: \frac{\text{kg m s}^{-2}}{\text{m}^2 \text{s}^{-2}} = \text{kg m}^{-1}.$$

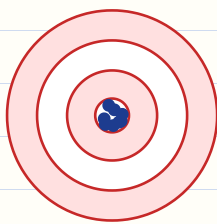
Worked example 4: prefixes and powers

Aluminium has density 2.7 g cm^{-3} . Express this in kg m^{-3} .

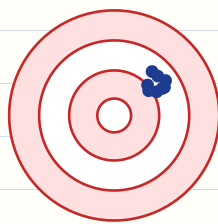
$$2.7 \text{ g} = 2.7 \times 10^{-3} \text{ kg and } 1 \text{ cm}^3 = (10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3. \text{ Density} = \frac{2.7 \times 10^{-3}}{10^{-6}} = 2.7 \times 10^3 \text{ kg m}^{-3}.$$

1.3 Errors and uncertainties

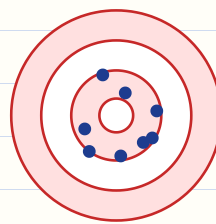
- **Random errors** make readings scatter unpredictably about the true value (e.g. reaction time with a stopwatch, reading a fluctuating meter). Reduce them by **repeating and averaging**, or by plotting a graph.
- **Systematic errors** shift every reading by the same amount or proportion in the same direction (e.g. a **zero error**, a wrongly calibrated scale, parallax always from the same side). Repeating does **not** reduce them; correct the zero error or recalibrate.
- **Precision**: how close repeated readings are to each other (small spread). **Accuracy**: how close a reading is to the true value.



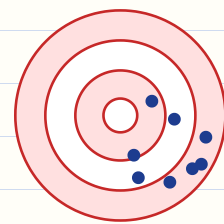
precise and accurate



precise, not accurate



accurate, not precise



neither

Precision is about the spread of the hits; accuracy is about where they are centred.



Random error: points scatter about the true line. A zero error shifts every reading by the same amount.

Combining uncertainties

absolute uncertainty Δx ; fractional uncertainty $\frac{\Delta x}{x}$; percentage uncertainty $\frac{\Delta x}{x} \times 100\%$

Sum or difference ($x = a \pm b$): **add the absolute uncertainties**: $\Delta x = \Delta a + \Delta b$

Product or quotient ($x = ab$ or a/b): **add the percentage uncertainties**

Power ($x = a^n$): **multiply the percentage uncertainty by n** (a constant such as π or 4 adds no uncertainty)

- Give the final absolute uncertainty to 1 (or 2) significant figures, and the value to the same decimal place: $g = 9.8 \pm 0.2 \text{ m s}^{-2}$, not 9.789 ± 0.177 .
- Subtracting two close values gives a large percentage uncertainty: $(25.0 \pm 0.5) - (21.0 \pm 0.5) = 4.0 \pm 1.0$, which is 25%.

Worked example 5: uncertainty in a density

A wire has mass $m = 12.4 \pm 0.1 \text{ g}$, diameter $d = 1.20 \pm 0.01 \text{ mm}$ and length $L = 1.500 \pm 0.002 \text{ m}$. Its density is $\rho = \frac{4m}{\pi d^2 L}$. Find ρ with its uncertainty.

$$\rho = \frac{4 \times 0.0124}{\pi \times (1.20 \times 10^{-3})^2 \times 1.500} = 7309 \text{ kg m}^{-3}.$$

$$\% \text{ uncertainty} = \frac{0.1}{12.4} + 2 \times \frac{0.01}{1.20} + \frac{0.002}{1.500} = 0.81\% + 1.67\% + 0.13\% = 2.6\%.$$

Absolute: $0.026 \times 7309 = 190$. So $\rho = (7.3 \pm 0.2) \times 10^3 \text{ kg m}^{-3}$. Notice d contributes most, because it is squared.

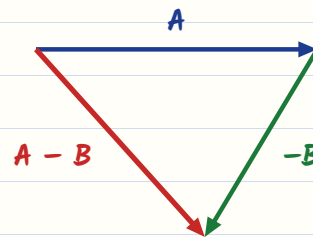
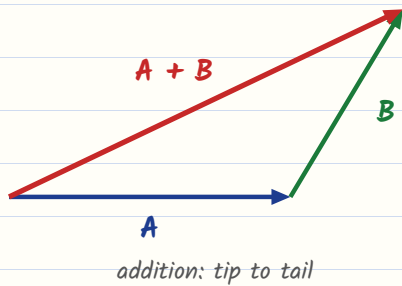
Worked example 6: zero error

A micrometer reads 0.03 mm when its jaws are closed. With a wire between the jaws it reads 1.27 mm. What is the diameter?

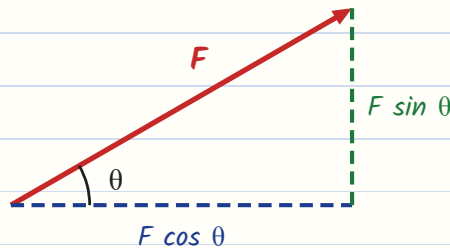
The zero error is +0.03 mm, so subtract it from every reading: $1.27 - 0.03 = 1.24 \text{ mm}$. Averaging repeated readings would not remove this error.

1.4 Scalars and vectors

- A **scalar** has **magnitude only**: distance, speed, mass, time, energy, power, temperature, charge, density, pressure.
- A **vector** has **magnitude and direction**: displacement, velocity, acceleration, force, weight, momentum, electric field strength.
- **Adding vectors**: draw them tip to tail; the resultant goes from the start of the first to the tip of the last.
Subtracting: $\mathbf{A} - \mathbf{B} = \mathbf{A} + (-\mathbf{B})$, where $-\mathbf{B}$ has the same size as $\mathbf{B}$ and the opposite direction (used for change in velocity, $\Delta \mathbf{v} = \mathbf{v} - \mathbf{u}$).

subtraction: add $-B$ (B reversed)

- **Resolving:** a vector F at angle θ to the horizontal has components $F \cos \theta$ (horizontal, next to θ) and $F \sin \theta$ (vertical, opposite θ). The components act at right angles and together replace F .
- To add vectors that are not at right angles, resolve each one, add the components, then combine: $R = \sqrt{R_x^2 + R_y^2}$, $\tan \alpha = \frac{R_y}{R_x}$.



Worked example 7: components

A rope pulls a sledge with a force of 40 N at 30° above the horizontal. Find the components.

Horizontal: $40 \cos 30^\circ = 34.6 \text{ N}$. Vertical: $40 \sin 30^\circ = 20.0 \text{ N}$.

Worked example 8: resultant by components

Forces of 6.0 N due east and 8.0 N at 60° north of east act on a point. Find the resultant.

$$R_x = 6.0 + 8.0 \cos 60^\circ = 10.0 \text{ N}; R_y = 8.0 \sin 60^\circ = 6.93 \text{ N}$$

$$R = \sqrt{10.0^2 + 6.93^2} = 12.2 \text{ N, at } \tan^{-1} \frac{6.93}{10.0} = 34.7^\circ \text{ north of east.}$$

Practical skills for Paper 3

Recording and uncertainties

- Record every reading to the precision of the instrument: a metre rule to the nearest mm (e.g. 0.452 m), a micrometer to 0.01 mm, a stopwatch to 0.01 s.
- Uncertainty in a single reading: usually the smallest division (or half of it); for a timing by hand, at least 0.1–0.2 s (reaction time).
- Uncertainty from repeated readings: **half the range**, $\Delta x = \frac{x_{\max} - x_{\min}}{2}$.
- Time many oscillations (e.g. 20) and divide: the reaction-time uncertainty is shared over 20 periods.

- **Tables:** each column headed with quantity and unit, e.g. T/s ; values in a column to the same number of decimal places.
- **Calculated values:** give the same number of significant figures as the least precise raw data (or one more).

Common mistakes that lose marks

- **Hertz is not a base unit:** frequency is s^{-1} . Intensity is power per area ($kg\ s^{-3}$), not the ampere just because it uses the symbol I .
- **Symbol equation missing:** to find base units, first write the defining equation (e.g. $P = W/t$), then substitute.
- **Differences have units:** a pressure difference $p_2 - p_1$ still has the units of pressure.
- **Powers in uncertainties:** saying "R is raised to the power 4" is not enough; you must say its percentage uncertainty is multiplied by 4.
- **sin and cos swapped** when resolving: the component next to the angle uses cos.
- **Units with prefixes:** mm^2 and cm^3 converted as if they were mm and cm.
- **Too many significant figures** in an uncertainty, or a value given to more decimal places than its uncertainty.

Exam-style multiple-choice questions (Paper 1 style)

20 questions, 1 mark each. Choose one answer, A, B, C or D. Answers with explanations follow the questions.

1. Which is an SI base unit?

- | | |
|----------|----------|
| A kelvin | B newton |
| C volt | D joule |

2. What are the SI base units of force?

- | | |
|-------------------|---------------------|
| A $kg\ m\ s^{-1}$ | B $kg\ m^2\ s^{-2}$ |
| C $kg\ m\ s^{-2}$ | D $kg\ s^{-2}$ |

3. What are the SI base units of power?

- | | |
|---------------------|---------------------|
| A $kg\ m^2\ s^{-2}$ | B $kg\ m^2\ s^{-3}$ |
| C $kg\ m\ s^{-3}$ | D $kg\ m^2\ s^{-1}$ |

4. Which quantity is a vector?

- | | |
|---------|------------|
| A speed | B energy |
| C mass | D momentum |

5. A radio signal has a frequency of 3.0 GHz. What is this in hertz?

- | | |
|----------------------------|-------------------------|
| A $3.0 \times 10^6\ Hz$ | B $3.0 \times 10^9\ Hz$ |
| C $3.0 \times 10^{12}\ Hz$ | D $3.0 \times 10^3\ Hz$ |

6. What is $25\ \mu m$ in metres?

- | | |
|---------------------------|---------------------------|
| A $2.5 \times 10^{-5}\ m$ | B $2.5 \times 10^{-6}\ m$ |
| C $2.5 \times 10^{-8}\ m$ | D $2.5 \times 10^{-4}\ m$ |

7. How can a systematic error in a measurement be reduced?
- A by repeating the reading and averaging
 - B by taking more readings over a wider range
 - C by recording to more significant figures
 - D by correcting for the zero error or recalibrating the instrument
8. Which statement describes a precise set of readings?
- A The mean is close to the true value.
 - B Each reading has many significant figures.
 - C The readings are close to each other.
 - D The readings are in SI units.
9. Which is the best estimate of the mass of an adult?
- A 70 kg
 - B 7 kg
 - C 700 kg
 - D 7000 kg
10. What are the SI base units of electric charge?
- A $A s^{-1}$
 - B $A s$
 - C A
 - D $kg A$
11. A length is measured as 20.0 ± 0.2 cm. What is the percentage uncertainty?
- A 0.2%
 - B 2%
 - C 1%
 - D 0.1%
12. $x = (12.0 \pm 0.1) - (8.0 \pm 0.1)$. What is the uncertainty in x ?
- A ± 0
 - B ± 0.1
 - C ± 0.05
 - D ± 0.2
13. $Z = \frac{P}{Q^2}$. The uncertainty in P is 2% and in Q is 3%. What is the percentage uncertainty in Z ?
- A 8%
 - B 5%
 - C 4%
 - D 11%
14. A force of 10 N acts at 60° to the horizontal. What is its horizontal component?
- A 8.7 N
 - B 5.0 N
 - C 10 N
 - D 6.0 N
15. Forces of 3 N and 4 N act on a body. Which cannot be the size of their resultant?
- A 1 N
 - B 5 N
 - C 7 N
 - D 8 N
16. Which equation is homogeneous?
- A $v = u + as$
 - B $s = ut + at$
 - C $v^2 = u^2 + 2as$
 - D $s = vt^2$

1 A · 2 C · 3 B · 4 D · 5 B · 6 A · 7 D · 8 C · 9 A · 10 B · 11 C · 12 D · 13 A · 14 B · 15 D · 16 C · 17 A ·
18 D · 19 B · 20 C

- ### Exam-style structured questions (Paper 2 style)

8

Question 1 [7 marks]

The speed v of a transverse wave on a stretched string is given by $v = \sqrt{\frac{T}{\mu}}$, where T is the tension in the string and μ is its mass per unit length.

- (a) Show that this equation is homogeneous. [3]
- (b) A string has $T = 64.0 \pm 0.8 \text{ N}$ and $\mu = (4.00 \pm 0.08) \times 10^{-3} \text{ kg m}^{-1}$. Calculate v . [1]
- (c) Determine the absolute uncertainty in v and state v with its uncertainty. [3]

Mark scheme

- (a) units of T : kg m s^{-2} ; units of μ : kg m^{-1} 1; $\frac{T}{\mu}$: $\text{m}^2 \text{s}^{-2}$, so $\sqrt{T/\mu}$: m s^{-1} 1; same as units of v , so homogeneous 1
- (b) $v = \sqrt{64.0/4.00 \times 10^{-3}} = 126 \text{ m s}^{-1}$ 1
- (c) % uncertainty = $\frac{1}{2}(1.25\% + 2.0\%)$ 1; = 1.6%, so $\Delta v = 2 \text{ m s}^{-1}$ 1; $v = 126 \pm 2 \text{ m s}^{-1}$ 1

Question 2 [8 marks]

A boat is steered due north at 3.0 m s^{-1} relative to the water. The river flows due east at 1.2 m s^{-1} . The river is 45 m wide.

- (a) Calculate the magnitude and direction of the resultant velocity of the boat. [3]
- (b) Calculate the time taken to cross the river and the distance the boat is carried downstream. [3]
- (c) Explain why velocity is a vector quantity but speed is a scalar quantity. [2]

Mark scheme

- (a) $\sqrt{3.0^2 + 1.2^2}$ 1; = 3.2 m s^{-1} 1; at $\tan^{-1}(1.2/3.0) = 22^\circ$ east of north 1
- (b) time = $45 \div 3.0$ 1; = 15 s 1; downstream $1.2 \times 15 = 18 \text{ m}$ 1
- (c) velocity has magnitude and direction 1; speed has magnitude only 1

Question 3 [8 marks]

A student determines the acceleration of free fall g with a simple pendulum of length $l = 0.500 \pm 0.002 \text{ m}$. She times 20 oscillations three times and obtains 28.4 s, 28.6 s and 28.2 s.

- (a) Explain why she times 20 oscillations rather than one. [1]
- (b) Calculate the period T and its absolute uncertainty. [3]
- (c) Use $g = \frac{4\pi^2 l}{T^2}$ to determine g and its absolute uncertainty. [3]
- (d) Suggest one source of systematic error in this experiment. [1]

Mark scheme

- (a) the reaction-time uncertainty is shared over 20 periods, so the percentage uncertainty in T is smaller 1
- (b) mean time 28.4 s, $T = 28.4 \div 20 = 1.42 \text{ s}$ 1; half range = 0.2 s for 20 oscillations 1; $\Delta T = 0.01 \text{ s}$ 1
- (c) $g = 4\pi^2 \times 0.500/1.42^2 = 9.79 \text{ m s}^{-2}$ 1; % uncertainty = $0.4\% + 2 \times 0.70\% = 1.8\%$ 1; $g = 9.8 \pm 0.2 \text{ m s}^{-2}$ 1

- (d) e.g. length measured to the top of the bob instead of its centre; or the stopwatch running slow

1

Quick-reference sheet

Item	Key facts
base units	kg, m, s, A, K; derived units from defining equations ($N = \text{kg m s}^{-2}$, $J = \text{kg m}^2 \text{s}^{-2}$, $W = \text{kg m}^2 \text{s}^{-3}$, $C = \text{A s}$, $V = \text{kg m}^2 \text{s}^{-3} \text{A}^{-1}$)
homogeneity	every term has the same base units; pure numbers have none
errors	random: scatter, reduce by averaging; systematic (zero error): same shift, correct or recalibrate
uncertainties	sum/difference: add absolute; product/quotient: add %; power n : $n \times \%$
vectors	tip to tail; $\mathbf{A} - \mathbf{B} = \mathbf{A} + (-\mathbf{B})$; components $F \cos \theta$, $F \sin \theta$

"I can" checklist

- ☐ state the five base units and write any derived unit in base units
- ☐ check an equation for homogeneity and find the units of a constant
- ☐ use the prefixes pico to tera, including with squared and cubed units
- ☐ explain random and systematic errors, precision and accuracy
- ☐ combine uncertainties for sums, products, quotients and powers
- ☐ add, subtract and resolve vectors