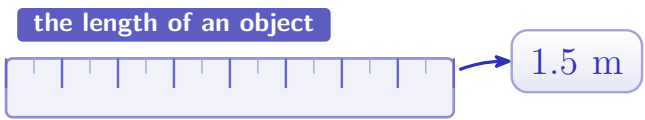
Physical Quantities & Units

AS Physics ▪ Topic 1

A-Level Physics



What we will cover

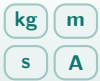
1 **Physical quantities**

sheet 1.1 · quantities



2 **SI units**

sheet 1.2 · units, prefixes



3 **Errors & uncertainties**

sheet 1.3 · uncertainty



4 **Scalars and vectors**

sheet 1.4 · add, resolve



5 **Putting it together**

definitions, exam tips, mistakes



1 Physical quantities

Sheet 1.1 – what you need to know

You must be able to:

- give every measurement a **number and a unit**
- tell a physical quantity from a unit
- make sensible estimates and orders of magnitude

What the exam asks

"What is essential when recording a measurement of a physical quantity?" **[1]**

"Which term represents a physical quantity?" **[1]**

"What is the best estimate of the wavelength of green light?" **[1]**

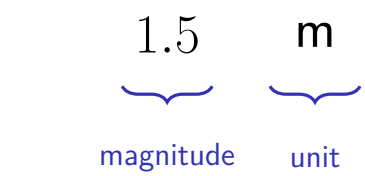
Practise on exercise sheet 1.1, then try the real exam questions on past-paper sheet 1.1.

A number *and* a unit

A **physical quantity** 物理量 has two parts:

- a **magnitude** 大小 – the number
- a **unit** 单位 – what the number means

The number alone tells you **nothing**.

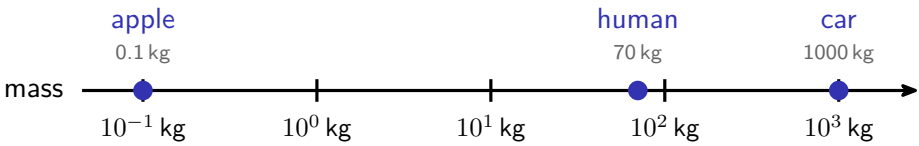


“1.5” ✗

“1.5 m” ✓

Estimate the everyday

A good estimate has the right **order of magnitude** 数量级 – the right power of ten. Paper 1 usually opens with one.



Each step along the line is a **factor of ten**. Pick the answer on the right step: a human is about $10^2\,\mathrm{kg}$, not 10^1 or 10^3.

Estimates to know by heart

human **mass** 质量

$70\,\mathrm{kg}$

human **weight** 重力

$700\,\mathrm{N}$

human height

$1.7\,\mathrm{m}$

an apple

$0.1\,\mathrm{kg}$

speed of sound in air

$340\,\mathrm{m\,s^{-1}}$

speed of light in a **vacuum** 真空

$3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$

free fall 自由落体

$g \approx 9.81\,\mathrm{m\,s^{-2}}$

An apple weighs about $1\,\mathrm{N}$. That one number lets you check every other force estimate.

More values to know

Sizes

- a car: $\sim 1000\,\mathrm{kg}$
- height of a room: $\sim 3\,\mathrm{m}$
- visible light wavelength: $\sim 5 \times 10^{-7}\,\mathrm{m}$
- **diameter** 直径 of an atom: $\sim 10^{-10}\,\mathrm{m}$; a nucleus: $\sim 10^{-15}\,\mathrm{m}$

Speeds and power

- walking: $\sim 1.5\,\mathrm{m\,s^{-1}}$
- a car on a fast road: $\sim 30\,\mathrm{m\,s^{-1}}$
- a kettle: $\sim 2\,\mathrm{kW}$
- a person climbing stairs: $\sim 300\,\mathrm{W}$

Materials and the air

- **density** 密度: water $1000\,\mathrm{kg\,m^{-3}}$, air $\sim 1.2\,\mathrm{kg\,m^{-3}}$, steel $\sim 8000\,\mathrm{kg\,m^{-3}}$
- **atmospheric pressure** 大气压强: $\sim 1.0 \times 10^{5}\,\mathrm{Pa}$
- room temperature: $\sim 20\,^{\circ}\mathrm{C} \approx 293\,\mathrm{K}$

> The right power of ten matters most: for a human, $70\,\mathrm{kg}$ is a good estimate; $7\,\mathrm{kg}$ is not.

Building an estimate

Not on the list? Build it from values that are.

Kinetic energy of a car

$m \approx 1000\,\mathrm{kg}$, $v \approx 30\,\mathrm{m\,s^{-1}}$:

$$\tfrac{1}{2}mv^2 \approx \tfrac{1}{2} \times 1000 \times 30^2 \approx 5 \times 10^5\,\mathrm{J}$$

Pressure under a standing person

weight $\approx 700\,\mathrm{N}$ on about $0.02\,\mathrm{m^2}$:

$$p \approx \frac{700}{0.02} \approx 4 \times 10^4\,\mathrm{Pa}$$

Always check that the **power of ten** looks sensible before you move on.

Quantity or unit? And how big?

"Which term represents a physical quantity?"

quantity	**unit**
spring constant	metre
temperature	kelvin
time	minute
percentage uncertainty *	ampere

*a pure number, but still a quantity.

Recording a measurement: a **number** and a **unit**, both essential.

Best estimate of the wavelength of green light?

$\lambda \approx 500\,\mathrm{nm} = 5 \times 10^{-7}\,\mathrm{m}$: visible light runs from about 400 to $700\,\mathrm{nm}$.

How many times larger is $2\,\mathrm{A}$ than $1\,\mathrm{mA}$?

$$\frac{2}{1 \times 10^{-3}} = 2000 \quad \text{and } 3.2\,\mathrm{MW} = 3200\,\mathrm{kW}.$$

2 SI units

Sheet 1.2 – what you need to know

You must be able to:

- express derived units in **base units**
- check an equation for homogeneity; find an unknown power
- convert prefixes, including squared and cubed

What the exam asks

"Which physical quantity could have units of $\mathrm{N\,s^2\,m^{-1}}$?" **[1]**

"The equation is homogeneous. What is the value of n?" **[1]**

"Determine the absolute uncertainty in c." **[2]**

Practise on exercise sheet 1.2, then try the real exam questions on past-paper sheet 1.2.

SI base quantities

The SI system has **seven base quantities** 基本量; these **five** are used here:

kg	**m**	**s**	**A**	**K**
mass	length	time	current	temperature

Combine them with $\times$ and $\div$ to get **every other unit** – N, J, W, Pa, ...

Build any derived unit

Each **derived unit** 导出单位 is just base units, from its defining equation:

N
newton 牛顿
force
$\mathrm{kg\,m\,s^{-2}}$

J
joule 焦耳
energy
$\mathrm{kg\,m^2\,s^{-2}}$

W
watt 瓦特
power
$\mathrm{kg\,m^2\,s^{-3}}$

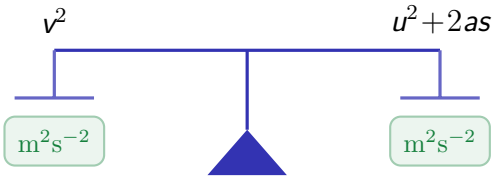
Pa
pascal 帕斯卡
pressure
$\mathrm{kg\,m^{-1}\,s^{-2}}$

Read the unit straight off the defining equation: **speed** 速率 $= \mathrm{m\,s^{-1}}$, **acceleration** 加速度 $= \mathrm{m\,s^{-2}}$, and **stress** 应力 is force per area, so it takes the pascal too.

Do the units balance?

Homogeneous 量纲一致 = both sides have the **same base units**. Test $v^2 = u^2 + 2as$:

- LHS $= \mathrm{m^2 s^{-2}}$
- $u^2 = \mathrm{m^2 s^{-2}}$; $2as = \mathrm{m^2 s^{-2}}$



> Matching units don't **prove** an equation right – but **mismatched** units prove it wrong.

Worked example – the units of a constant

Drag force $F = kv^2$: base units of k?

Rearrange: $k = F/v^2$. In base units,

$$k: \quad \frac{\mathrm{kg\,m\,s^{-2}}}{\mathrm{m^2\,s^{-2}}} = \mathrm{kg\,m^{-1}}$$

"Which equation could be correct?"

- write each option in **base units**
- only a **homogeneous** equation *can* be correct
- a pure number (2, π, $\frac{1}{2}$) has **no unit**, so it never changes the check

Units run backwards: find the quantity, find the power

Which quantity could have units $\mathrm{N\,s^2\,m^{-1}}$?

$$\mathrm{N\,s^2\,m^{-1}} = \mathrm{kg\,m\,s^{-2}} \cdot \mathrm{s^2} \cdot \mathrm{m^{-1}} = \mathrm{kg}$$

a **mass**. Always reduce to base units first.

Cubed and squared prefixes

$$1\,\mathrm{g\,cm^{-3}} = \frac{10^{-3}\,\mathrm{kg}}{(10^{-2}\,\mathrm{m})^3} = 1000\,\mathrm{kg\,m^{-3}}$$

$$1\,\mathrm{kN\,mm^{-2}} = \frac{10^{3}\,\mathrm{N}}{(10^{-3}\,\mathrm{m})^2} = 10^9\,\mathrm{Pa}$$

$T = 2\pi\left(\frac{L}{g}\right)^n$ is homogeneous. Find n.

$$\mathrm{s} = \left(\frac{\mathrm{m}}{\mathrm{m\,s^{-2}}}\right)^n = \left(\mathrm{s^2}\right)^n = \mathrm{s}^{2n}$$

$$2n = 1 \;\Rightarrow\; n = \tfrac{1}{2}$$

Match the power of **each** base unit on both sides; 2π has no unit.

Prefixes – powers of ten

A **prefix** 词头 scales a unit by a power of ten.

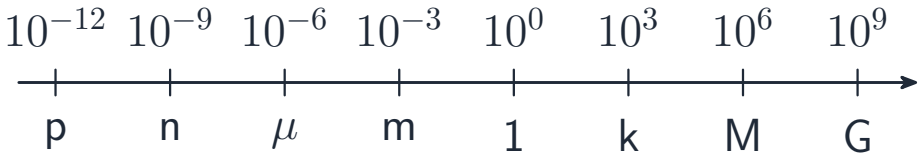
n	μ	m	1	k	M	G
nano	micro	milli	base	kilo	mega	giga
10^{-9}	10^{-6}	10^{-3}	10^{0}	10^{3}	10^{6}	10^{9}

each step is $\times 10^3$

smaller ← → larger

Also learn: **T** tera 10^{12} **d** deci 10^{-1} **c** centi 10^{-2} **p** pico 10^{-12}

Prefixes on the page



Each step is a factor of 1000, so converting is a shift of three places – never a new calculation.

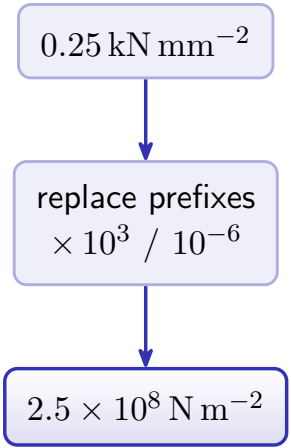
> **Square the prefix too**: $1\,\mathrm{mm}^2 = (10^{-3}\,\mathrm{m})^2 = 10^{-6}\,\mathrm{m}^2$, not 10^{-3}.

Worked example – converting prefixes

$0.25\,\mathrm{kN\,mm^{-2}} \to \mathrm{N\,m^{-2}}$

Replace each prefix – and **square** the mm:

$$0.25\,\frac{10^{3}}{(10^{-3})^{2}} = 2.5\times10^{8}\,\mathrm{N\,m^{-2}}.$$



3 Errors and uncertainties

Sheet 1.3 – what you need to know

You must be able to:

- tell **precision** from **accuracy**, systematic from random error
- combine uncertainties through sums, products and powers
- decide whether two results agree

What the exam asks

"Which set of results has a high precision and a low accuracy?" **[1]**

"State and explain whether cube A and cube B could be made from the same material." **[2]**

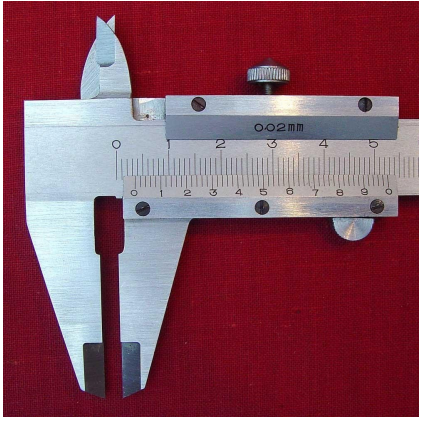
"Use SI base units to show that n is equal to -2." **[2]**

Practise on exercise sheet 1.3, then try the real exam questions on past-paper sheet 1.3.

Every measurement is uncertain

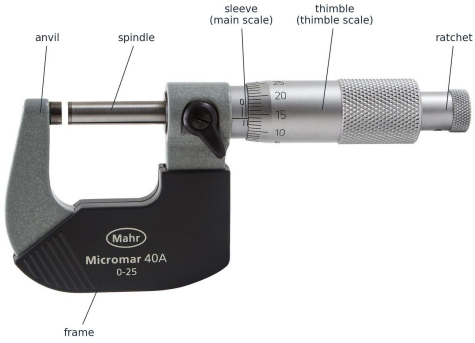
Every measurement carries some **uncertainty** 不确定度. A good experimenter:

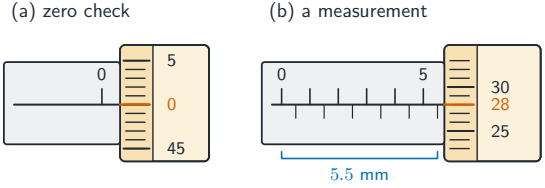
- knows where it comes from
- estimates it fairly
- carries it to the answer



Calipers measure with a small uncertainty

The micrometer – to $0.01\,\mathrm{mm}$



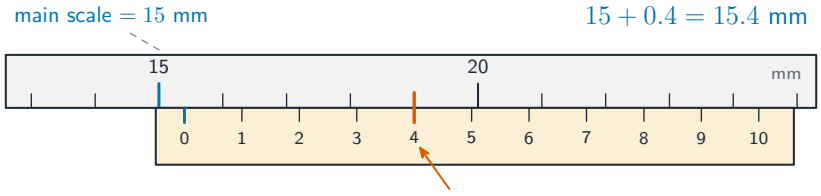


reads 0.00 mm

$5.5 + 0.28 = 5.78$ mm

A **micrometer** 千分尺 reads to $0.01\,\mathrm{mm}$: reading = **sleeve** (main scale) + **thimble** scale.

The vernier caliper – to $0.1\,\mathrm{mm}$

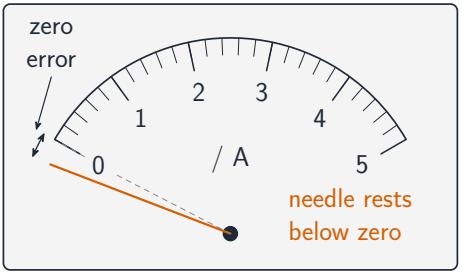


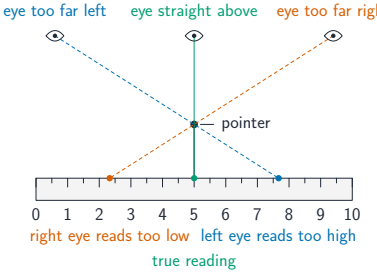


Whole mm from the **main scale**, then tenths from the **vernier** mark that lines up.

Systematic errors

A **systematic error** 系统误差 shifts every reading by the same amount, in the same direction. Causes: a **zero error** 零点误差, a **calibration** 校准 error, **parallax** 视差.

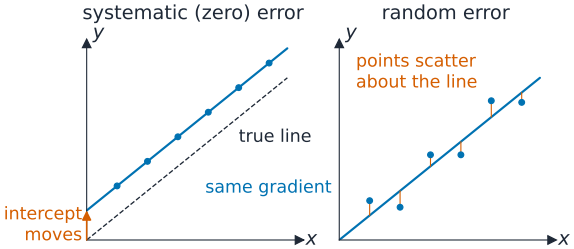




It spoils accuracy, not precision, and repeating cannot reveal it. **Reduce it**: subtract the zero error; calibrate against a known standard; read the scale from directly in front.

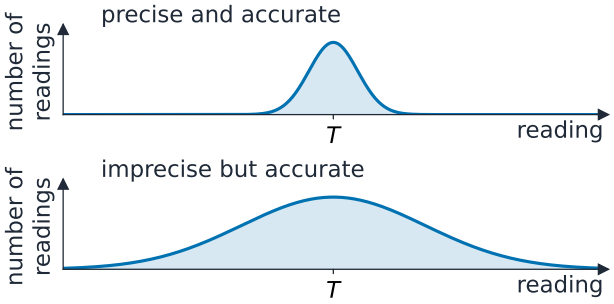
Random errors

A **random error** 随机误差 scatters readings above and below the true value at random. On a graph it scatters the points; a systematic error moves the **intercept** 截距.



It spoils the precision. **Causes**: how you read the scale, changing conditions, the smallest step the **instrument** 仪器 shows. **Reduce it**: take the **mean** 平均值 of many repeats; use smaller divisions; time many oscillations, not one.

Precision 精密度: how narrow is the spread?

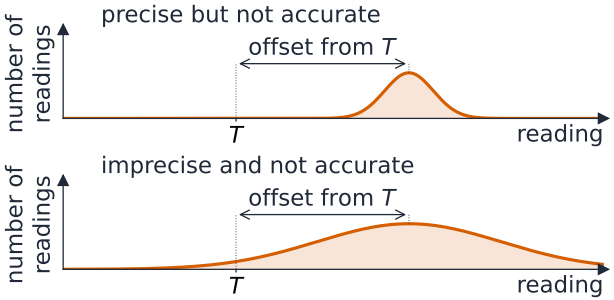


precision: how closely repeated readings agree
(random error / spread)

precision 精密度: how close repeated readings are to each other.

- precise readings are **grouped** close together
- the narrower the curve, the more precise
- **random** errors spoil it

Accuracy 准确度: is the peak on the true value?



accuracy: how close readings are to the true value
(systematic error reduces accuracy)

accuracy 准确度: how close a reading – or the mean of several – is to the **true value**.

- a peak away from T is **not accurate**
- **systematic** errors spoil it
- with enough repeats, the mean can still be accurate despite random errors

Precise, accurate, both or neither

precise and accurate

close together, near the true value

precise, not accurate

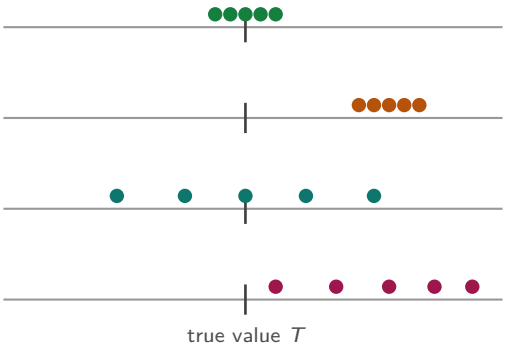
close together, away from it: systematic error

accurate, not precise

spread out, but the mean is near it

neither

spread out, and away from the true value



In a table of repeated readings, judge the spread (precision) and the mean (accuracy) separately.

The uncertainty in one reading

analogue: ± half a division

A metre rule reads to $1\,\mathrm{mm}$, so one reading is $\pm 0.5\,\mathrm{mm}$. A length needs **two** readings, so $\pm 1\,\mathrm{mm}$.

digital: ± 1 in the last digit

A stopwatch showing $2.47\,\mathrm{s}$ is $\pm 0.01\,\mathrm{s}$.

timing by hand

Your **reaction time** 反应时间 matters more than the display: allow ± 0.1 to $0.2\,\mathrm{s}$, and time **many** oscillations.

repeats: ± half the range 极差的一半

2.42, 2.48, $2.45\,\mathrm{s}$: mean $2.45\,\mathrm{s}$, range $0.06\,\mathrm{s}$, so $t = (2.45 \pm 0.03)\,\mathrm{s}$.

Be honest: a shadow edge that is hard to see is uncertain by several mm, however fine the scale. "The smallest **division** 分度" is not accepted for a difficult reading.

Combining uncertainties

A **derived quantity** 导出量 is one you *calculate* from measured values. Each is $x \pm \Delta x$; its **percentage uncertainty** 百分比不确定度 $= \frac{\Delta x}{|x|} \times 100\%$.

- **add / subtract** $\Rightarrow$ add **absolute uncertainty** 绝对不确定度
- **multiply / divide** $\Rightarrow$ add the %
- **power** $a^n \Rightarrow$ multiply % by $|n|$

$$y = \frac{a\,b}{c}$$

$$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

Adding or subtracting – add the *absolute* uncertainties

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

Both $y = a + b$ and $y = a - b$ add them.

> A difference keeps the whole Δ but has a far smaller value, so its % is the worst of the three.

$a = (50.0 \pm 0.5)\,\text{mm}$  1.0%

$b = (20.0 \pm 0.2)\,\text{mm}$  1.0%

$a - b = (30.0 \pm 0.7)\,\text{mm}$  2.3%

one scale for all three – the *difference* is the widest

Multiplying or dividing – add the *percentage* uncertainties

$$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

Density $\rho = \dfrac{m}{V}$ from
$m = (250 \pm 1)\,\mathrm{g}$ and
$V = (100 \pm 2)\,\mathrm{cm}^3$.

> The bigger % wins: improve V, not m.

$$\frac{\Delta m}{m} = \frac{1}{250}$$ 0.4%

$$\frac{\Delta V}{V} = \frac{2}{100}$$ 2.0%

$$\frac{\Delta \rho}{\rho}$$ 2.4%

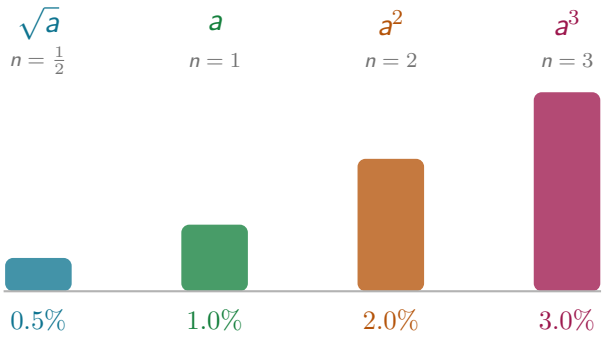
$$\rho = (2.50 \pm 0.06)\,\mathrm{g\,cm^{-3}}$$

Powers – multiply the percentage by the index

$$\frac{\Delta y}{|y|} = |n| \frac{\Delta a}{|a|}$$

A 1% error in a length becomes 3% in a volume – three edges each carry it.

Next slide: d carries 0.38%, so $V \propto d^3$ carries 1.14%.



each bar is the % uncertainty in y when a carries 1%

Worked example – uncertainty in a volume



$d = (5.26 \pm 0.02)\,\text{cm}$ $\qquad V = \frac{\pi}{6} d^3 = 76.2\,\text{cm}^3$

1 **% uncertainty in d**

$$\frac{0.02}{5.26} \times 100\% = 0.38\%$$

2 **$V \propto d^3$: triple it**

$$3 \times 0.38\% = 1.14\%$$

3 **back to absolute**

$$1.14\% \times 76.2$$

$\Delta V = 0.9\,\text{cm}^3$

$$V = (76.2 \pm 0.9)\,\text{cm}^3$$

Making the uncertainty small

Which instrument for a $2\,\mathrm{mm}$ wire, to within 1%?

1% of $2\,\mathrm{mm}$ is $0.02\,\mathrm{mm}$, so:

metre rule	$1\,\mathrm{mm}$
vernier caliper	$0.1\,\mathrm{mm}$
micrometer	$0.01\,\mathrm{mm}$

Time 20 swings, not one

Reaction time $\pm 0.2\,\mathrm{s}$ on $20T$: $\Delta T = \frac{0.2}{20} = 0.01\,\mathrm{s}$.

$g = \dfrac{4\pi^2 L}{T^2}$, with L to 1% and T to 2%

$\%g = \%L + 2 \times \%T = 1 + 4 = 5\%$

A sphere's volume is known to 6%. The radius?

$V \propto r^3$, so $r \propto V^{1/3}$:
$\%r = \frac{1}{3} \times 6\% = 2\%$

> A power n multiplies the percentage by $|n|$; a root divides it.

Do two values agree?

Do not just say "they are close". Work out the **percentage difference** 百分比差异:

$$\frac{|k_1 - k_2|}{\text{mean of } k_1 \text{ and } k_2} \times 100\%$$

Smaller than the percentage uncertainty in k (or the criterion given, often 10%): the values **agree** and the relationship is supported. **Larger**: they do not.

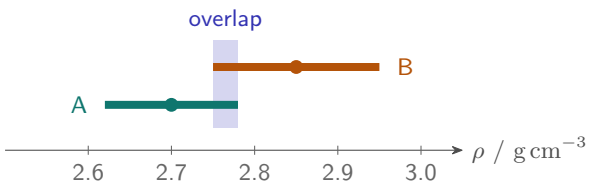
Test against a 10% criterion

$k_1 = 2.46$, $k_2 = 2.61$: difference 0.15, mean 2.535.

$$\frac{0.15}{2.535} \times 100\% = 5.9\%$$

$5.9\% < 10\%$, so the values agree.

Do the ranges overlap?



Cube A: $2.70 \pm 0.08\,\mathrm{g\,cm^{-3}}$**; cube B:** $2.85 \pm 0.10\,\mathrm{g\,cm^{-3}}$**. "Could they be made from the same material?" [2]**

A: 2.62 to 2.78; B: 2.75 to 2.95.

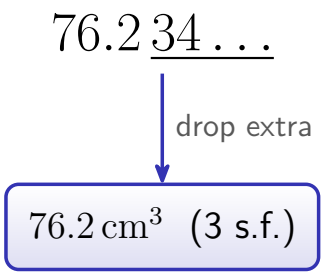
The ranges **overlap**, so yes, they could.

No overlap: the values do **not** agree.
Overlap: they **could** be the same, not that they must be.

Significant figures

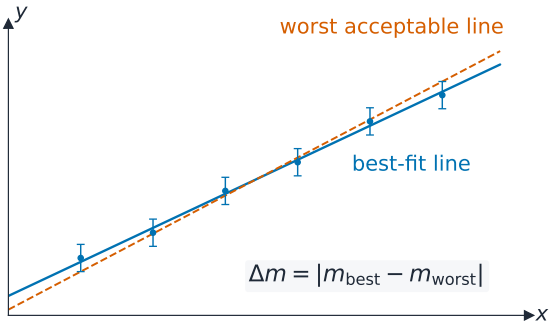
Give the answer the **same number of significant figures 有效数字** as the least precise measurement you used – usually 2 or 3.

- too many looks too exact; too few loses information
- **justify** it by naming the raw readings: "*a* has 2 s.f. because *L* and *t* were measured to 2 s.f."
- "because of the raw data" alone earns **no mark**; in a table, judge each row from its own least precise reading



Uncertainties on a graph

- an **error bar** 误差棒 on each point: its length is the absolute uncertainty
- draw the **line of best fit** 最佳拟合直线, then the **worst acceptable line** 最差可接受直线: the steepest (or shallowest) line through **every** bar
- $\Delta m = |m_{\text{best}} - m_{\text{worst}}|$, the intercept the same way; its % flows into anything calculated from m



Plotting a logarithm? The uncertainty in $\ln x$ is $\Delta x/x$ ($0.434\,\Delta x/x$ in $\lg x$): work it out for the largest and smallest x.

4 Scalars and vectors

Sheet 1.4 – what you need to know

You must be able to:

- add vectors by drawing and by calculation
- resolve a vector into two perpendicular components
- find the range of a resultant, and a change in velocity

What the exam asks

"What is not a possible magnitude of the resultant force?" **[1]**

"What are the values of θ and v?" **[1]**

"Compare scalar and vector quantities." **[2]**

Practise on exercise sheet 1.4, then try the real exam questions on past-paper sheet 1.4.

Size only, or size *and* direction?

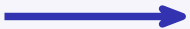
Scalar 标量

$5\,\mathrm{kg}$

magnitude only

mass · time · temperature · energy
work · power · speed · distance
pressure · density
electric charge 电荷

Vector 矢量



magnitude + direction

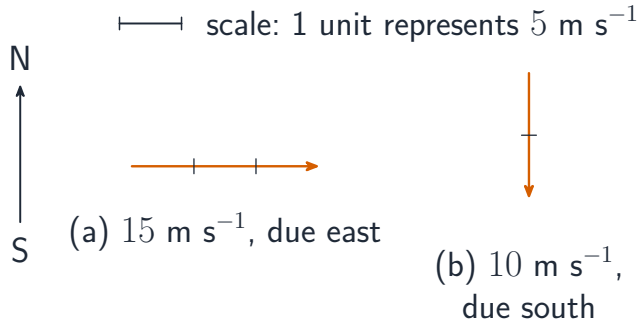
displacement 位移 · velocity
acceleration · momentum 动量
force (including weight)

> Quick test – can you ask "in which direction?" If yes, it is a vector.

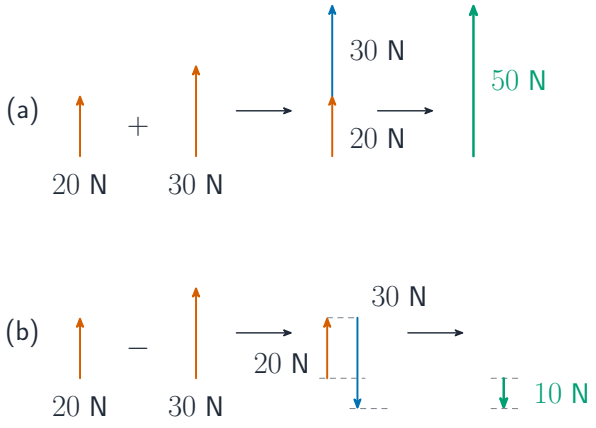
Drawing vectors to scale

A vector is an arrow:

- direction of arrow = direction
- length (to scale) = magnitude

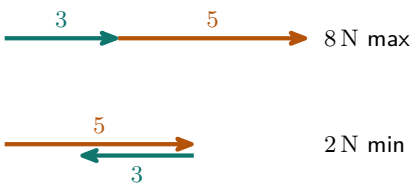


Adding tip to tail



- add **coplanar** 共面 vectors tip to tail
- the **resultant** 合矢量 runs first tail → last tip
- to subtract $\vec{X} - \vec{Y}$, add the reverse of $\vec{Y}$

The smallest and largest resultant



Two forces $3\,\mathrm{N}$ and $5\,\mathrm{N}$: the resultant is anywhere from 2 to $8\,\mathrm{N}$.

Forces of 2, 4 and $7\,\mathrm{N}$. Which resultant is not possible?

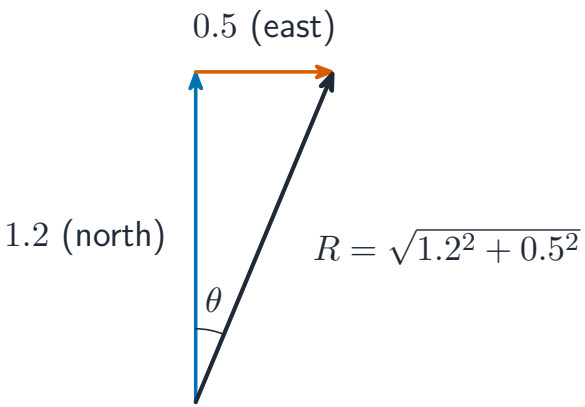
Max: all in line, $2 + 4 + 7 = 13\,\mathrm{N}$.

Min: 7 against the other two, $7 - (2 + 4) = 1\,\mathrm{N}$.

So 0 is **impossible**: 7 is longer than $2 + 4$, and the triangle cannot close.

Three forces can give zero only if the largest is no bigger than the **sum** of the other two.

Vectors at right angles



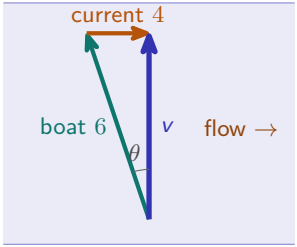
For **perpendicular** 垂直 vectors:

$$|\vec{R}| = \sqrt{X^2 + Y^2}, \quad \tan\theta = \frac{Y}{X}$$

Swimmer

$1.2\,\mathrm{m\,s^{-1}}$ north, current $0.5\,\mathrm{m\,s^{-1}}$ east: $|\vec{R}| = 1.3\,\mathrm{m\,s^{-1}}$, $\theta \approx 23^\circ$ east of north.

Aiming upstream to cross straight over



A boat moves at $6.0\,\mathrm{m\,s^{-1}}$ through water flowing at $4.0\,\mathrm{m\,s^{-1}}$. It must cross straight over. Find θ and v.

$$\sin\theta = \frac{4.0}{6.0} \Rightarrow \theta = 42^\circ \text{ upstream}$$

$$v = \sqrt{6.0^2 - 4.0^2} = 4.5\,\mathrm{m\,s^{-1}}$$

The boat's **velocity through the water** is the hypotenuse here, not the resultant.

Two equal forces at an angle

Same size F, with 2α between them:

$$R = 2F\cos\alpha$$

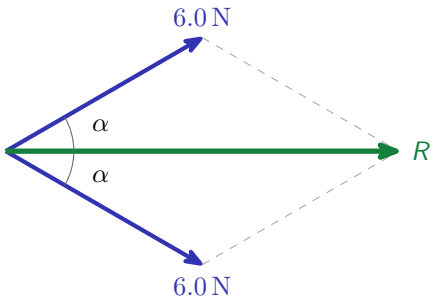
along the line that **cuts the angle in half**.

Two $6.0\,\mathrm{N}$ forces, $60°$ apart

$\alpha = 30°$, so

$$R = 2 \times 6.0 \times \cos 30° = 10.4\,\mathrm{N}$$

Any other angle: a **scale drawing** 按比例作图 of the vector triangle, or resolve both into components and recombine with $\sqrt{X^2 + Y^2}$.



Worked example – a change in velocity

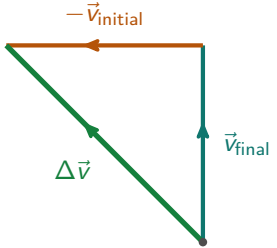
East at $5.0\,\mathrm{m\,s^{-1}}$, then north at $5.0\,\mathrm{m\,s^{-1}}$

A change in velocity is a **vector subtraction**:

$$\Delta\vec{v} = \vec{v}_{\text{final}} - \vec{v}_{\text{initial}}$$

Draw 5.0 north, then add the **reverse** of the initial velocity, 5.0 west:

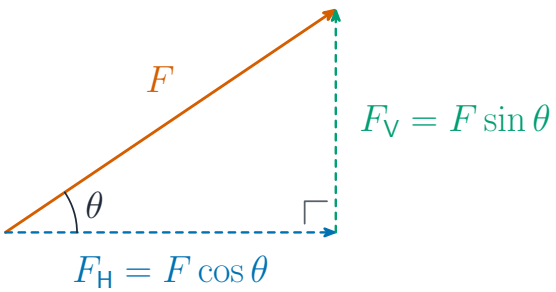
$$|\Delta\vec{v}| = \sqrt{5.0^2 + 5.0^2} = 7.1\,\mathrm{m\,s^{-1}} \text{ north-west}$$



The **speed** did not change, but the **velocity** did – so a resultant force must have acted (topic 3).

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Resolving into components

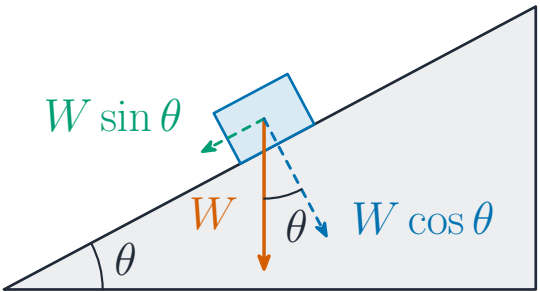


Split into two **perpendicular** 垂直 **components** 分量 – usually **horizontal** 水平 and **vertical** 竖直, or along and across a surface:

$$F_\mathrm{H} = F\cos\theta, \quad F_\mathrm{V} = F\sin\theta$$

Resolve when you need how much of a vector acts in **one direction**: a force along a slope, or a ball's horizontal and vertical velocity.

Weight on a slope



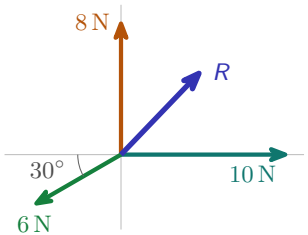
On an **inclined plane** 斜面, split the weight along the slope and at right angles to it:

$$W_{\parallel} = W\sin\theta, \quad W_{\perp} = W\cos\theta$$

where θ is the **angle of the slope** to the horizontal.

> The angle between W and the perpendicular to the slope is **the slope angle** θ too.

Worked example – three forces by components



Find the resultant of the three forces.

$$\Sigma F_x = 10 - 6\cos 30^\circ = 10 - 5.2 = 4.8\,\text{N}$$

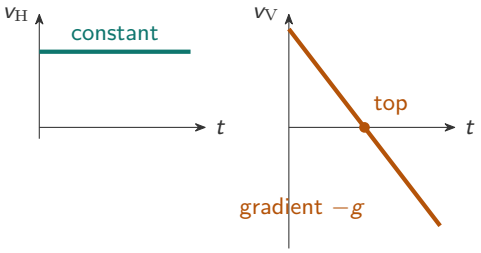
$$\Sigma F_y = 8 - 6\sin 30^\circ = 8 - 3.0 = 5.0\,\text{N}$$

$$R = \sqrt{4.8^2 + 5.0^2} = 6.9\,\text{N}$$

$$\theta = \tan^{-1}\frac{5.0}{4.8} = 46^\circ \text{ above the } 10\,\text{N}$$

Resolve every force, add the x and y parts **with signs**, then recombine.

A projectile's two components against time



- horizontal: **no force**, so $v_{\mathrm{H}} = u\cos\theta$ all flight
- vertical: starts at $u\sin\theta$, falls **steadily**, zero at the top, then negative
- the two parts are **independent**

Resolve the launch velocity first; each component then has its own graph.

5 Putting it together

Definitions the examiner accepts

A definition is marked against **fixed wording**: learn these exactly, and give one answer only.

physical quantity	物理量	a numerical magnitude together with a unit
homogeneous equation	量纲一致	an equation in which every term has the same base units
scalar	标量	a quantity with magnitude only
vector	矢量	a quantity with magnitude and direction
precision	精密度	how close repeated readings are to each other
accuracy	准确度	how close a reading, or the mean of several readings, is to the true value

Definitions: errors and uncertainties

Five more, marked the same way:

systematic error	系统误差	an error that shifts every reading in the same direction by the same amount; not reduced by repeating
random error	随机误差	an error that scatters readings above and below the true value; reduced by repeating and averaging
zero error	零点误差	the reading an instrument shows when the true value is zero
absolute uncertainty	绝对不确定度	the range within which the true value is expected to lie, in the units of the quantity
percentage uncertainty	百分比不确定度	the absolute uncertainty divided by the value, multiplied by 100%

Exam tips

- Give every answer a **unit**, and check **homogeneity** – both sides of an equation must have the same base units.
- Distinguish **random error** (reduce by repeating and averaging) from **systematic error** (a zero or calibration error that repeats do not remove).
- Combine uncertainties: **add absolute** uncertainties when adding/subtracting, **add percentage** uncertainties when multiplying/dividing (and multiply the % by any power).
- Distinguish **precision** (small spread) from **accuracy** (close to the true value).
- Resolve a vector into perpendicular components ($F\cos\theta$, $F\sin\theta$); add vectors tip-to-tail or by components.

Common mistakes

✗ The mistake	✓ What is right
Substituting $5\,\mathrm{cm}$ as 5, or $20\,\mathrm{g}$ as 20.	Convert the prefix first: $0.05\,\mathrm{m}$, $0.020\,\mathrm{kg}$.
The same % uncertainty for T^2 as for T.	**Squaring doubles** the % uncertainty; a square root halves it.
Treating the % uncertainty and the absolute uncertainty as the same number.	Absolute is in the **units** of the quantity; percentage is $\Delta x/x \times 100\%$.
"The smallest division" as the uncertainty of a hard reading.	Estimate **honestly**: a difficult edge can be uncertain by several mm.
Two answers to a definition.	**Commit to one**.

6 Recap

Topic 1 – key takeaways

1 Magnitude + unit

every quantity is a number *and* a unit

2 Derived units

built from 5 base units; check **homogeneity**

3 Precision vs accuracy

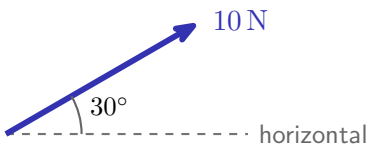
spread of repeats vs the true value

4 Vectors

add tip-to-tail; resolve into components

Check yourself

1. SI base units of the **pascal**?
2. Readings close together, far from the true value: precise or accurate?
3. $y = ab^2$: how do the % uncertainties combine?
4. $10\,\mathrm{N}$ at 30°: horizontal component?



for question 4

Try all four first – the answers appear on the next slide.

Check yourself

1. SI base units of the **pascal**?

   $\Rightarrow \mathrm{kg\,m^{-1}\,s^{-2}}$

2. Readings close together, far from the true value: precise or accurate?

   $\Rightarrow$ **precise**, not accurate

3. $y = ab^2$: how do the % uncertainties combine?

   $\Rightarrow \frac{\Delta y}{y} = \frac{\Delta a}{a} + 2\,\frac{\Delta b}{b}$

4. $10\,\mathrm{N}$ at $30°$: horizontal component?

   $\Rightarrow 10\cos 30° = \mathbf{8.7\,N}$



for question 4