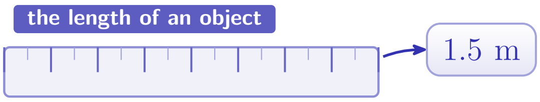
Physical Quantities & Units

AS Physics ▪ Topic 1

A-Level Physics



What we will cover

1. Physical quantities
2. SI units & prefixes
3. Errors & uncertainties
4. Scalars & vectors
5. Recap & self-check

1 Physical quantities

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

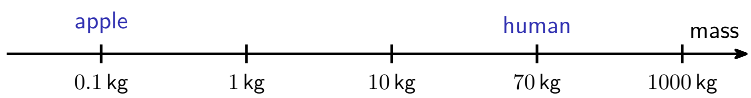
The number alone tells you nothing.

$$\underbrace{1.5}_{\text{magnitude}} \quad \underbrace{\text{m}}_{\text{unit}}$$

"1.5" ✗ | "1.5 m" ✓

Estimate the everyday

A good estimate has the right **order of magnitude** 数量级.



body weight $\approx 700\,\mathrm{N}$ | sound $\approx 340\,\mathrm{m\,s^{-1}}$ | light $\approx 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$ | $g \approx 9.81\,\mathrm{m\,s^{-2}}$

2 SI units

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 × and ÷ 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:

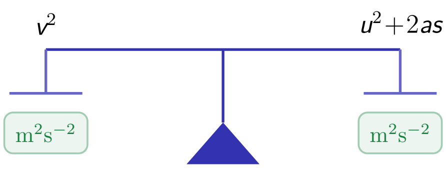
N	**J**	**W**	**Pa**
force	energy	power	pressure
$\mathrm{kg\,m\,s^{-2}}$	$\mathrm{kg\,m^2\,s^{-2}}$	$\mathrm{kg\,m^2\,s^{-3}}$	$\mathrm{kg\,m^{-1}\,s^{-2}}$

e.g. **force** $= m \times a \;\Rightarrow\; \mathrm{kg\,m\,s^{-2}} =$ **N**.

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.

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 →

Prefixes on the page

10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{0}	10^{3}	10^{6}	10^{9}
p	n	μ	m	1	k	M	G

each step is $\times 10^3$

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

Worked example – converting prefixes

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

Replace each prefix – and square the mm:

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

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

↓

replace prefixes
$\times 10^3$ / 10^{-6}

↓

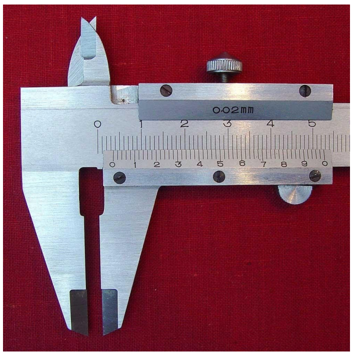
$2.5\times10^{8}\,\mathrm{N\,m^{-2}}$

3 Errors and uncertainties

Every measurement is uncertain

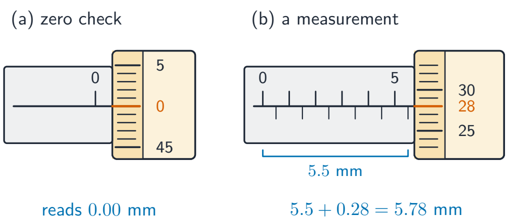
Every measurement carries some **uncertainty** 不确定度. A good experimenter:

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



Calipers measure with a small uncertainty

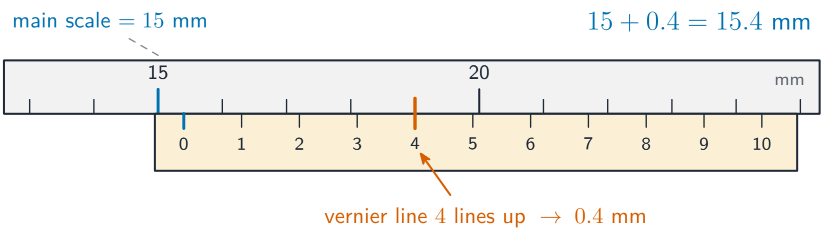
The micrometer – to $0.01\,\mathrm{mm}$



Reading = sleeve (main scale) + thimble scale.

> A **micrometer** 千分尺 reads to $0.01\,\mathrm{mm}$: sleeve + thimble.

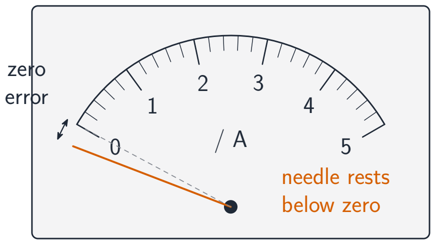
The vernier caliper – to $0.1\,\mathrm{mm}$



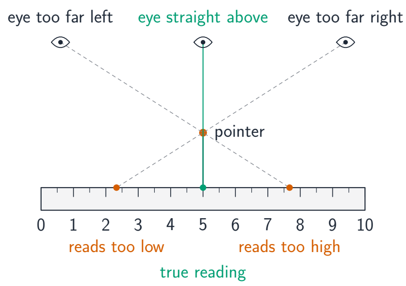
Whole mm from the main scale
+ tenths from the lined-up
vernier mark.

Systematic vs random errors

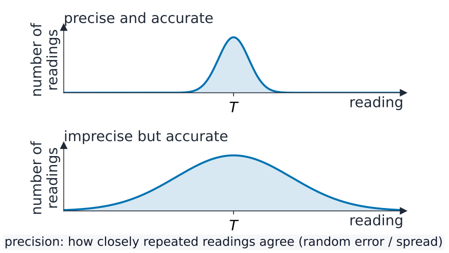
systematic error **系统误差** – same shift every time (**zero error** 零点误差, **calibration** 校准, **parallax** 视差).

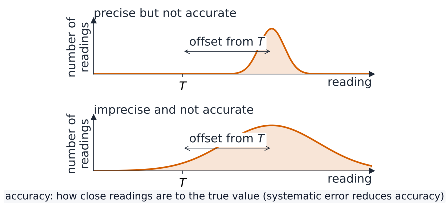


random error **随机误差** – scatters with no pattern; the mean of many repeats cancels it.



Precision vs accuracy





accuracy *准确度: peak on true value?*

precision *精密度: how narrow*

Combining uncertainties

Value $x \pm \Delta x$; **percentage uncertainty** 百分比不确定度 $= \frac{\Delta x}{|x|} \times 100\%$.

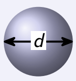
- **add / subtract** $\Rightarrow$ add **absolute uncertainty** 绝对不确定度
- **multiply / divide** $\Rightarrow$ add the %
- **power** a^n $\Rightarrow$ multiply % by $|n|$

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

$$\downarrow$$

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

Worked example – uncertainty in a volume



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

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

$1.14\% \times 76.2$

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

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

Significant figures

> Match the **significant figures** 有效数字 to the least precise measurement – usually 2 or 3.

- too many $\Rightarrow$ looks too exact
- too few $\Rightarrow$ loses information

$$76.2\,\underline{34\ldots}$$

$$\downarrow \text{ drop extra}$$

$$\boxed{76.2\,\mathrm{cm}^3 \quad (3\text{ s.f.})}$$

4 Scalars and vectors

Size only, or size *and* direction?

Scalar 标量

$5\,\mathrm{kg}$

magnitude only

mass · time · energy
speed · distance · density

Vector 矢量

magnitude + direction

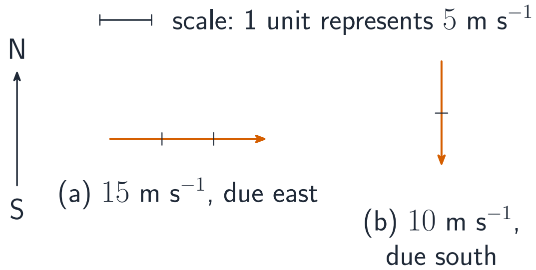
displacement 位移 · velocity
force · momentum 动量

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

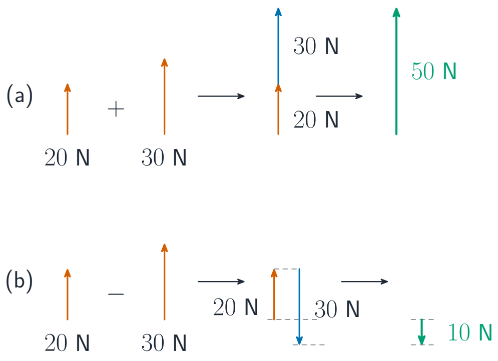
Drawing vectors to scale

A vector is an arrow:

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

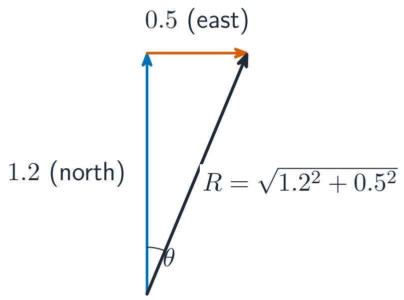


Adding tip to tail



- 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 $\vec{Y}$

Vectors at right angles



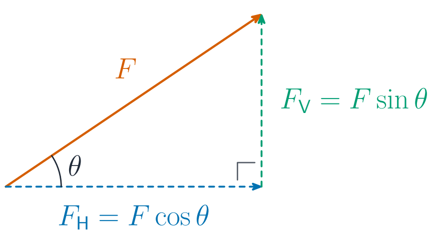
For **perpendicular** 垂直 vectors:

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

Swimmer

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

Resolving into components



Split into perpendicular **components** 分量:

$$v_H = v\cos\theta, \quad v_V = v\sin\theta.$$

On an **inclined plane** 斜面:

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

5 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

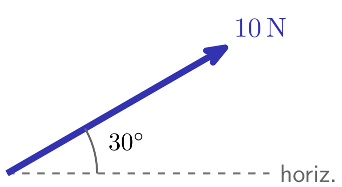
spread of repeats vs the true value

4 Vectors

add tip-to-tail; resolve into components

Check yourself

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



for question 4

Answers **1.** $\mathrm{kg\,m^{-1}s^{-2}}$ **2.** precise, not accurate **3.** $\frac{\Delta y}{y} = \frac{\Delta a}{a} + 2\frac{\Delta b}{b}$ **4.** $8.7\,\mathrm{N}$