Chapter 1: Physical quantities and units

Physical Quantities

> A physical quantity is a feature of something of which can be measured.

For example, the length of a ruler, the speed of a car, the time taken to run a kilometer, these all use physical quantities. It is vital to use units when mentioning these quantities.

For e.g., 1 cm is vastly different from 1 kilometer, and 1 second is different from 1 hour.

SI Quantities and base units

> SI is founded upon seven fundamental or base units. The base units each have a unique definition agreed at world conventions.

This SI quantity will be the quantities you use in physics.

Base quantity	base unit/SI unit	symbol
mass	kilogram	kg
length	meter	m
time	second	s
electric current	ampere(amp)	A
temperature	kelvin	K

Base quantity	base unit/SI unit	symbol
amount of substance	mole	mol
luminous intensity	candela	cd

Each quantity can have larger or smaller values(multiples) which can be denoted using prefixes.

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

So 1 kilometer would be $1 \times 10^3\ m$ or $1\ km$ and 1 centimeter would be

$1 \times 10^{-2}\ m$ or $1\ cm$.

💡 Note that for mass, the SI quantity and unit start from kilogram, not gram.

Order of magnitude of quantities

It is useful to be able to estimate or guess the order of magnitude, or in simple terms, the size of a measurement.

> The order of magnitude is the power of 10 to which the number is raised.

💡 This estimation can be useful especially when you are not sure of your answer.

For e.g., the acceleration of free fall is $9.8\,m\,s^{-2}$. If your calculations have led you to a value of $a = 9800\,m\,s^{-2}$, you know you have gone wrong somewhere, and so you can recheck.

Derived units

All quantities, aside from the base units can be called derived units.

> Derived units consist of some combination of the base units. The base units may be multiplied together or divided by one another, but never added or subtracted.

Here are some examples.

quantity	unit	derived unit
frequency	hertz (Hz)	s^{-1}
velocity	$m\,s^{-1}$	$m\,s^{-1}$
acceleration	$m\,s^{-2}$	$m\,s^{-2}$
force	newton (N)	$kg\,m\,s^{-2}$

Checking equations

> In any equation where each term has the same base units, the equation is said to be homogeneous or ‘balanced’.

In $v = u + at$, each term has the $m\,s^{-1}$ term, so it is balanced.

If the equation is not balanced, it is wrong.

Errors and uncertainties

Different tools of measurements have different levels of accuracy. For example, a ruler has less accuracy than a micrometer screw gauge at measuring small items.

Absolute and percentage uncertainty

$12 \pm 0.1\,cm$

This shows the uncertainty of the measurement. This means that the measurement can be anywhere from $11.9\,cm$ to $12.1\,cm$.

> The total range of values within which the measurement is likely to lie is known as its uncertainty.

In the example above, $0.1\,cm$ is the **absolute uncertainty**. To find the **percentage uncertainty**, we do this:

$$\pm \frac{\text{uncertainty}}{\text{measurement}} \times 100$$

So, for the example it would be $\pm \frac{0.1}{12} \times 100 = 0.83\%$

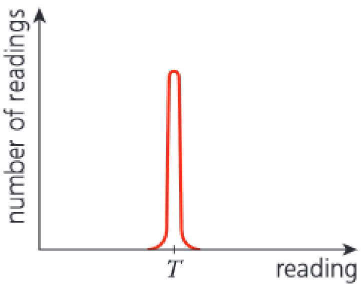
💡 Note that the uncertainty should be stated to 1 significant figure.

The measurement should also not have more significant figures than the uncertainty. For e.g., $12.22 \pm 0.1\ cm$ is wrong.

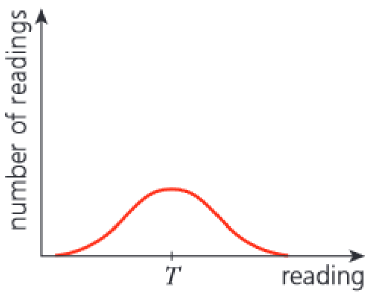
Accuracy and precision

> Accuracy refers to the closeness of a measured value to the ‘true’ or ‘known’ value.

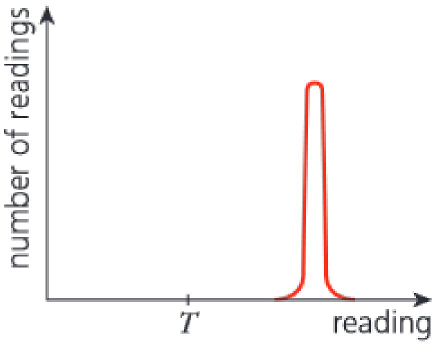
> Precision refers to how close a set of measured values are to each other.



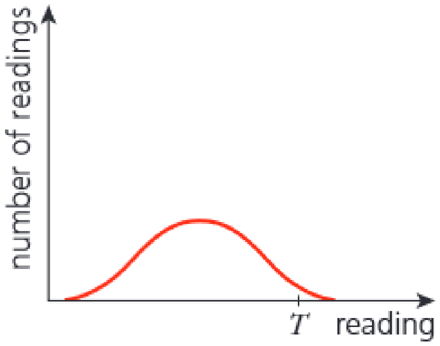
a) precise and accurate



b) imprecise but accurate



a) precise but not accurate



b) imprecise and not accurate

Judging from these diagrams, you can probably know that the closer the values are, the more precise they are, regardless of being close to the desired value.

Accuracy is when the mean of the values are close to the desired value.

Choice of instruments

If you want to measure a strand of hair, you would not use a ruler, right? You would use a micrometer screw gauge. You should be able to decide which instrument to use, especially in the practical exam.

Systematic and random errors

Systematic errors

A systematic error will result in all measurements being shifted up or down in a constant rate. Here, it is not possible to repeat the experiment and find averages for an accurate measurement. Instead, you should do improve the measuring system itself.

Here are some systematic errors:

- zero error
    - The measurement is not taking place starting from zero. For example, you might be measuring length starting from the ruler’s edge rather than zero(which is most of the time not at the edge)

- wrongly calibrated scale
    - Sometimes, the scales we use are not correctly calibrated. A balance might be reading 500 grams as 600 grams. The solution is to recalibrate the scale.

- reaction time of experimenter
    - When timings are carried out manually, the experimenter will always react and measure the timing slightly slower than the actual time. To reduce this, the interval of measurement should be greater than the reaction time(around 1 tenths of a second).
    - For example, when measuring the oscillation of a pendulum, the total time of the swing should be at least 10 seconds, so that 1 tenths of a second don’t matter much.

Random errors

This results in measurements being scattered around the acceptable value. To fix this, repeat and average measurements, and draw best-fit graphs.

Some examples are:

- reading a scale wrongly (parallax error, etc)
- timing oscillations without a reference marker, so each timing might not be a full swing

- taking readings of a quantity that varies with time, so you would have to read 2 scales at once

Combining uncertainties

Sometimes you have to combine 2 or more measurements, and in that case, you would have to combine their uncertainties too.

💡

1. When adding or subtracting measurements, you add the uncertainties.
2. When multiplying or dividing measurements, you add the fractional(percentage) uncertainties.

Scalars and vectors

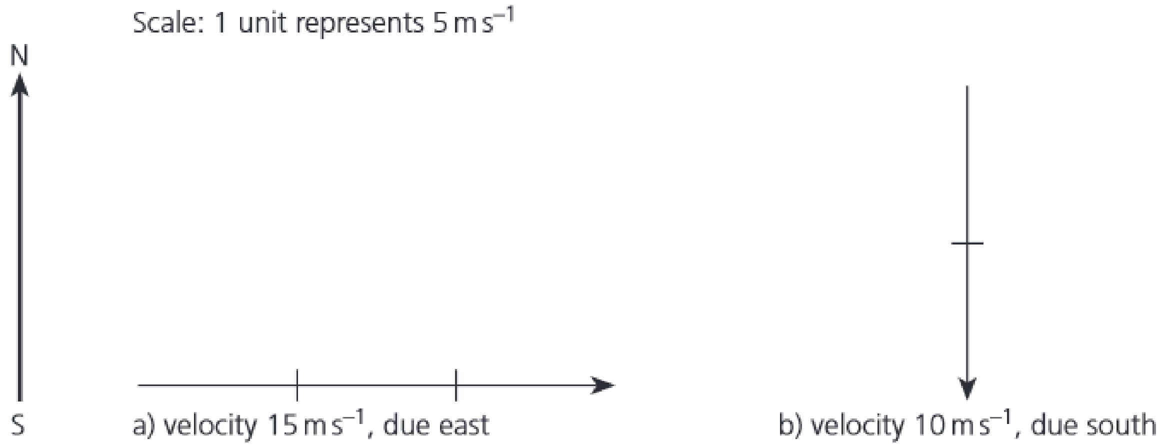
> A quantity which can be described fully by giving its magnitude and unit is known as a scalar quantity. They can be added algebraically.

> A vector quantity has magnitude, unit and direction. They may not be added algebraically.

For example, mass is a scalar quantity because 1 kg of mass does not have a direction. But 1 newton of weight has a direction towards the center of the Earth.

Vector representation

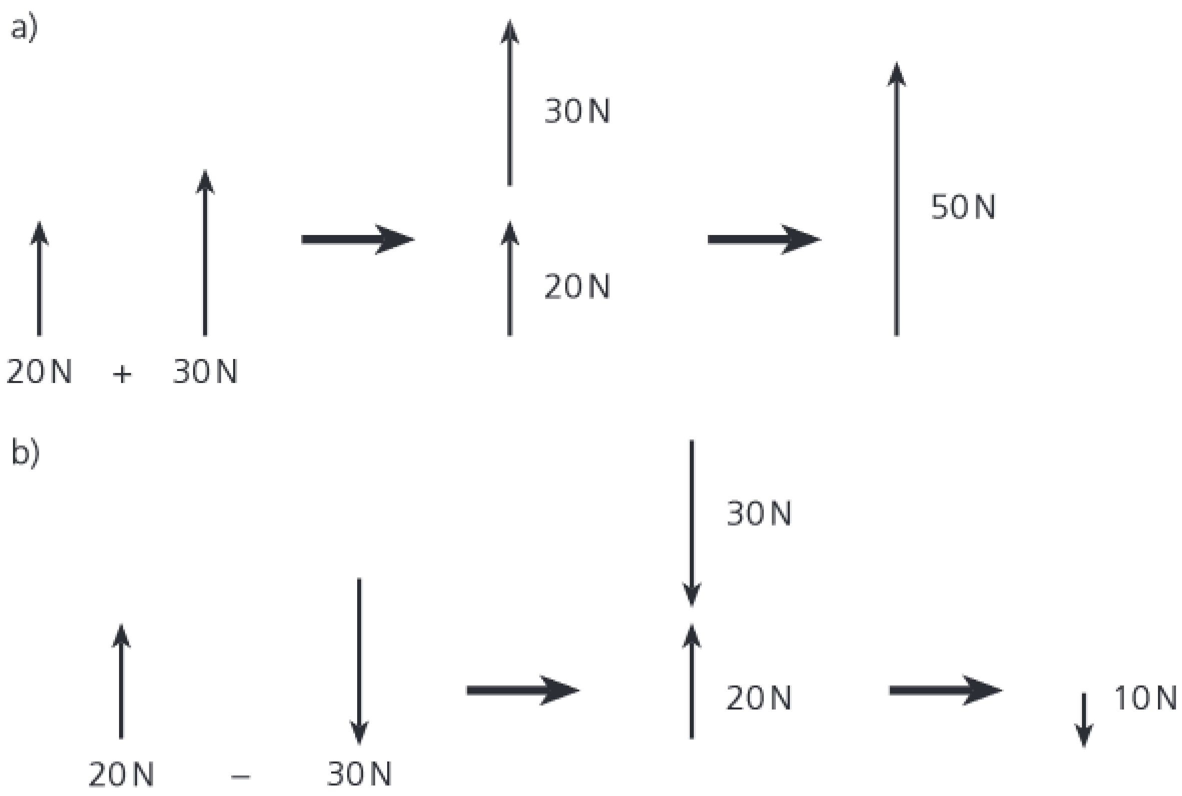
You can use arrows to represent vectors. This makes it simple and clear to understand and also shows the direction of the vector.



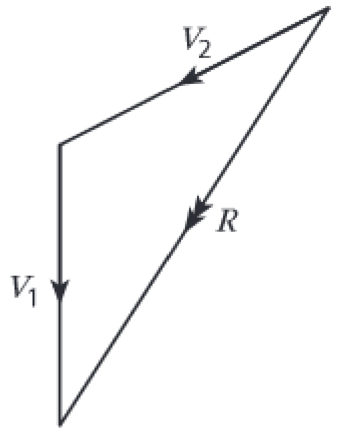
Addition of vectors

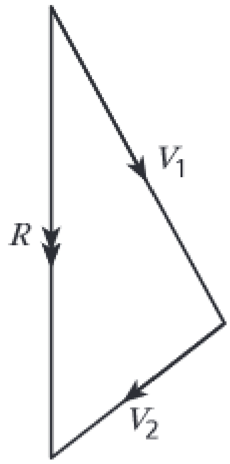
Depending on the direction of vectors, the calculations might vary. For example, if there are 2 vectors facing north with magnitude $20\,N$ and $30\,N$, the resultant vector is $20 + 30 = 50\,N$.

But if one vector faces north with $20\,N$, and the other faces south with $30\,N$, the resultant vector is $20 - 30 = -10\,N$!



If the vectors are not opposite in direction, then a **vector triangle** is used.





In a vector triangle, we get a resultant vector R in a new direction.

💡 Note that you connect the vectors from head to tail.

If a right angle triangle is formed, the Pythagorean theorem can be used to find the resultant vector.