EXAM PAPERS PRACTICE

A Level Physics CIE

1. Physical Quantities & Units

CONTENTS

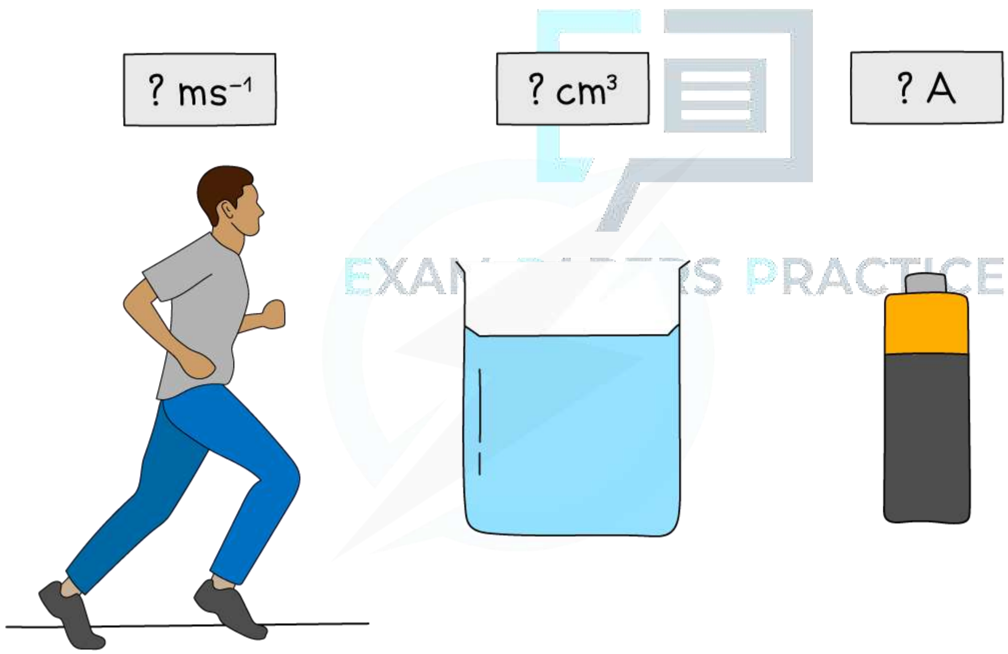
EXAM PAPERS PRACTICE

1.1 Physical Quantities & Units

1.1.1 Physical Quantities

What is a Physical Quantity?

- Speed and velocity are examples of physical quantities; both can be measured
- All physical quantities consist of a numerical magnitude and a unit
- In physics, every letter of the alphabet (and most of the Greek alphabet) is used to represent these physical quantities
- These letters, without any context, are meaningless
- To represent a physical quantity, it must contain both a numerical value and the **unit** in which it was measured
- The letter *v* be used to represent the physical quantities of velocity, volume or voltage
- The units provide the context as to what *v* refers to
    - If *v* represents velocity, the unit would be **m s^{-1}**
    - If *v* represents volume, the unit would be **m^3**
    - If *v* represents voltage, the unit would be **V**



All physical quantities must have a numerical magnitude and a unit

Estimating Physical Quantities

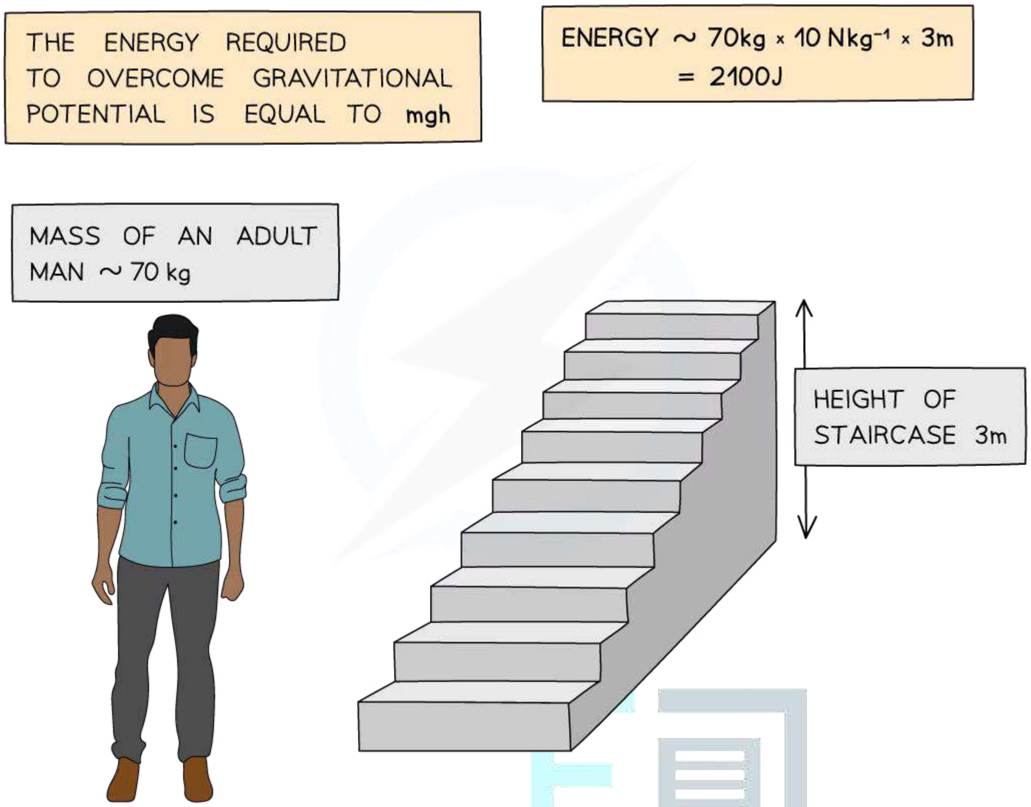
- There are important physical quantities to learn in physics
- It is useful to know these physical quantities, they are particularly useful when making estimates
- A few examples of useful quantities to memorise are given in the table below (this is by no means an exhaustive list)

Estimating Physical Quantities Table

QUANTITY	SIZE
DIAMETER OF AN ATOM	10^{-10} m
WAVELENGTH OF UV LIGHT	10 nm
HEIGHT OF AN ADULT HUMAN	2 m
DISTANCE BETWEEN THE EARTH AND THE SUN (1 AU)	1.5×10^{11} m
MASS OF A HYDROGEN ATOM	10^{-27} kg
MASS OF AN ADULT HUMAN	70 kg
MASS OF A CAR	1000 kg
SECONDS IN A DAY	90000 s
SECONDS IN A YEAR	3×10^{7} s
SPEED OF SOUND IN AIR	300 ms^{-1}
POWER OF A LIGHTBULB	60W
ATMOSPHERIC PRESSURE	1×10^{5} Pa

? Worked Example

Estimate the energy required for an adult man to walk up a flight of stairs.



Exam Tip

The mark scheme for calculations involving estimates are normally quite generous and offer a range of values as the final answer. Some common estimates are:

- Mass of an adult = 70 kg
- Gravitational field strength, g = 10 m s^{-2}
- Mass of a car = 1500 kg
- Wavelength of visible light = 400 nm (violet) – 700 nm (red)

Many values are already given in your data booklet that therefore may not be given in the question, so make sure to check there too!

SI Base Quantities

- There is a seemingly endless number of units in Physics
- These can all be reduced to six base units from which every other unit can be derived
- These seven units are referred to as the SI Base Units; this is the only system of measurement that is officially used in almost every country around the world

SI Base Quantities Table

QUANTITY	SI BASE UNIT	SYMBOL
MASS	KILOGRAM	kg
LENGTH	METRE	m
TIME	SECOND	s
CURRENT	AMPERE	A
TEMPERATURE	KELVIN	K
AMOUNT OF SUBSTANCE	MOLE	mol

Exam Tip

You will only be required to use the first five SI base units in this course, so make sure you know them!

Derived Units

- Derived units are derived from the seven SI Base units
- The base units of physical quantities such as:
  - Newtons, **N**
  - Joules, **J**
  - Pascals, **Pa,** can be deduced
- To deduce the base units, it is necessary to use the definition of the quantity
- The Newton (N), the unit of force, is defined by the equation:
  - Force = mass × acceleration
  - $N = kg \times m\ s^{-2} = kg\ m\ s^{-2}$
  - Therefore, the Newton (N) in SI base units is $\mathbf{kg\ m\ s^{-2}}$
- The Joule (J), the unit of energy, is defined by the equation:
  - Energy = ½ × mass × velocity^2
  - $J = kg \times (m\ s^{-1})^2 = kg\ m^2\ s^{-2}$
  - Therefore, the Joule (J) in SI base units is $\mathbf{kg\ m^2\ s^{-2}}$
- The Pascal (Pa), the unit of pressure, is defined by the equation:
  - Pressure = force ÷ area
  - $Pa = N \div m^2 = (kg\ m\ s^{-2}) \div m^2 = kg\ m^{-1}\ s^{-2}$
  - Therefore, the Pascal (Pa) in SI base units is $\mathbf{kg\ m^{-1}\ s^{-2}}$

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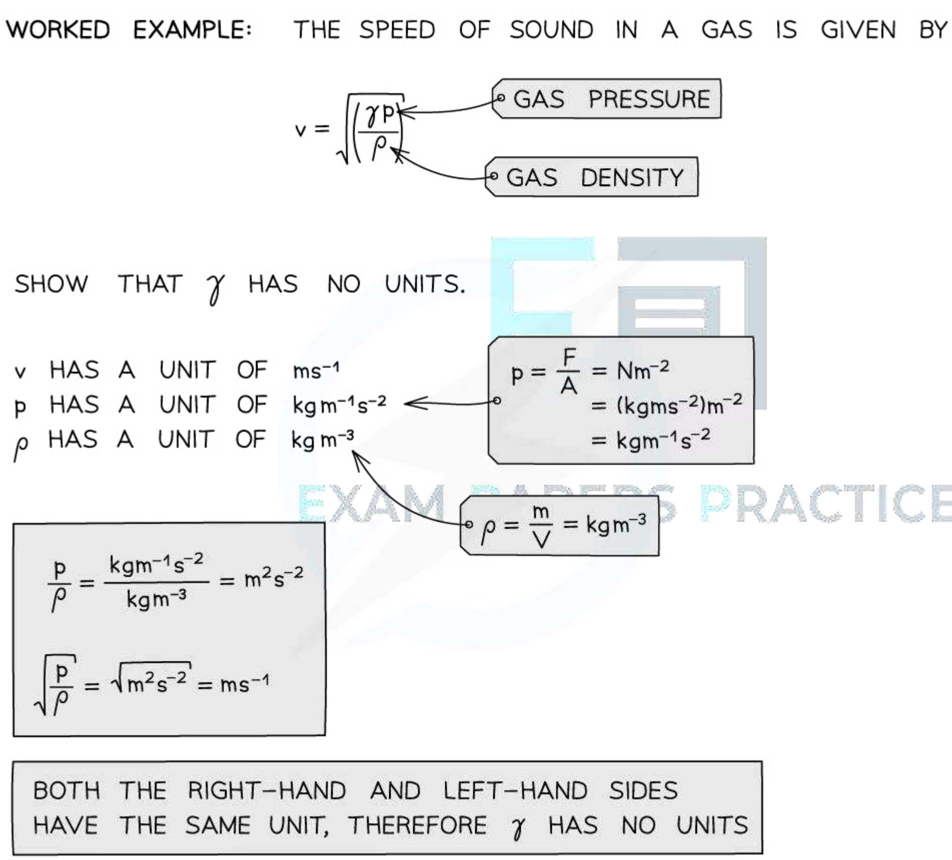
1.1.3 Homogeneity of Physical Equations & Powers of Ten

Homogeneity of Physical Equations

- An important skill is to be able to check the homogeneity of physical equations using the SI base units
- The units on either side of the equation should be the same
- To check the homogeneity of physical equations:
  - Check the units on both sides of an equation
  - Determine if they are equal
  - If they do not match, the equation will need to be adjusted



How to check the homogeneity of physical equations

Powers of Ten

- Physical quantities can span a huge range of values
- For example, the diameter of an atom is about 10^{-10} m (0.0000000001 m), whereas the width of a galaxy may be about 10^{21} m (1000000000000000000000 m)
- This is a difference of 31 powers of ten
- Powers of ten are numbers that can be achieved by multiplying 10 times itself
- It is useful to know the prefixes for certain powers of ten

Powers of Ten Table

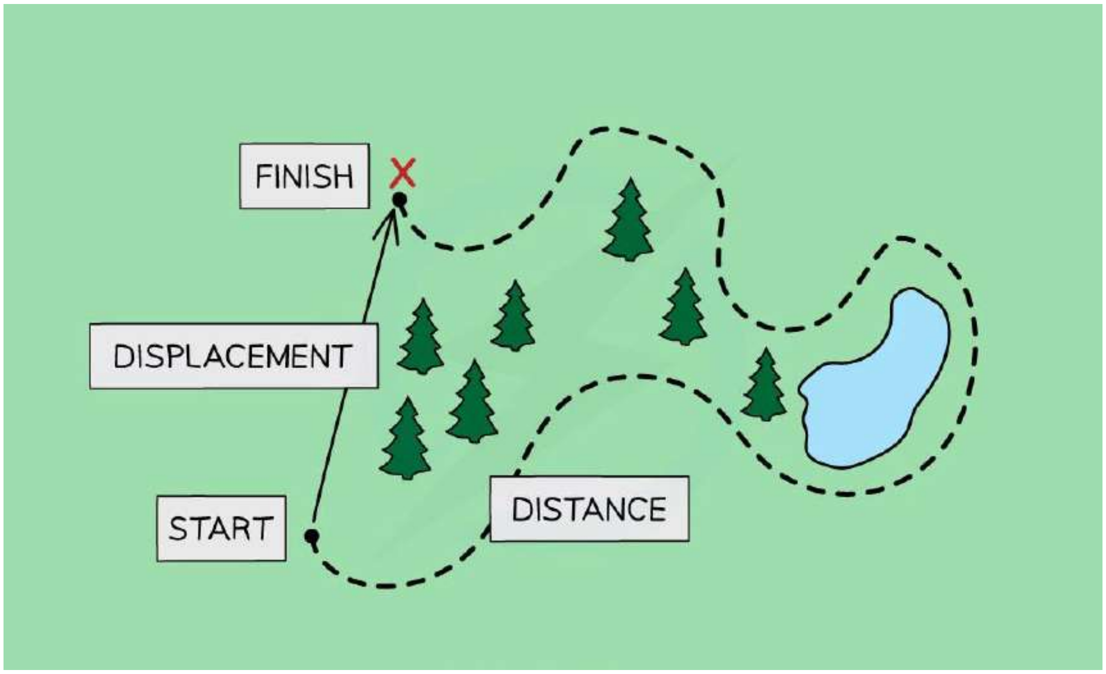
PREFIX	ABBREVIATION	POWER OF TEN
TERA–	T	10^{12}
GIGA–	G	10^{9}
MEGA–	M	10^{6}
KILO–	k	10^{3}
CENTI–	c	10^{-2}
MILLI–	m	10^{-3}
MICRO–	μ	10^{-6}
NANO–	n	10^{-9}
PICO–	p	10^{-12}

Exam Tip

You will often see very large or very small numbers categorised by powers of ten, so it is very important you become familiar with these as getting these prefixes wrong is a very common exam mistake!

What are Scalar & Vector Quantities?

- A **scalar** is a quantity which **only** has a magnitude (size)
- A **vector** is a quantity which has **both** a magnitude and a direction
- For example, if a person goes on a hike in the woods to a location which is a couple of miles from their starting point
  - As the crow flies, their **displacement** will only be a few miles but the **distance** they walked will be much longer



Displacement is a vector while distance is a scalar quantity

- **Distance** is a scalar quantity because it describes how an object has travelled overall, but not the direction it has travelled in
- **Displacement** is a vector quantity because it describes how far an object is from where it started and in what direction
- There are a number of common scalar and vector quantities

Scalars and Vectors Table

SCALARS	VECTORS
DISTANCE	DISPLACEMENT
SPEED	VELOCITY
MASS	ACCELERATION
TIME	FORCE
ENERGY	MOMENTUM
VOLUME	
DENSITY	
PRESSURE	
ELECTRIC CHARGE	
TEMPERATURE	

Exam Tip

Do you have trouble figuring out if a quantity is a vector or a scalar? Just think – can this quantity have a minus sign? For example – can you have negative energy? No. Can you have negative displacement? Yes!

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Combining Vectors

- **Vectors** are represented by an arrow
  - The arrowhead indicates the **direction** of the vector
  - The length of the arrow represents the **magnitude**

- Vectors can be combined by **adding** or **subtracting** them from each other
- There are two methods that can be used to combine vectors: the **triangle method** and the **parallelogram method**
- To combine vectors using the triangle method:
  - **Step 1:** link the vectors head-to-tail
  - **Step 2:** the resultant vector is formed by connecting the tail of the first vector to the head of the second vector

- To combine vectors using the parallelogram method:
  - **Step 1:** link the vectors tail-to-tail
  - **Step 2:** complete the resulting parallelogram
  - **Step 3:** the resultant vector is the diagonal of the parallelogram

- When two or more vectors are added together (or one is subtracted from the other), a single vector is formed and is known as the **resultant** vector

Vector Addition

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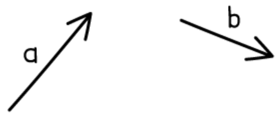
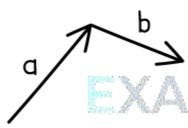
? Draw the vector c = a + b

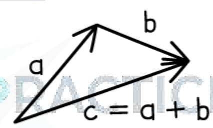


TRIANGLE METHOD

STEP 1: LINK THE VECTORS HEAD-TO-TAIL

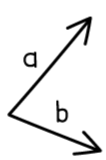


STEP 2: FORM THE RESULTANT VECTOR FROM LINKING THE TAIL OF a TO THE HEAD OF b

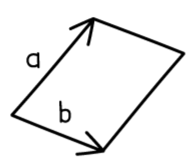


PARALLELOGRAM METHOD

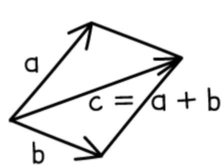
STEP 1: LINK THE VECTORS TAIL-TO-TAIL



STEP 2: COMPLETE THE RESULTING PARALLELOGRAM



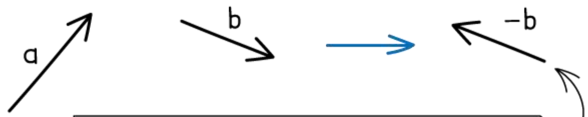
STEP 3: THE RESULTANT VECTOR IS THE DIAGONAL OF THE PARALLELOGRAM



Vector Subtraction

For more help, please visit www.exampaperspractice.co.uk

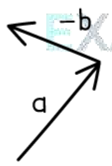
Draw the vector c = a - b



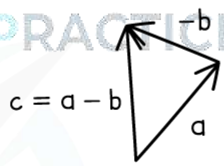
FIRST REVERSE THE DIRECTION OF VECTOR b TO MAKE −b

TRIANGLE METHOD

STEP 1: LINK THE VECTORS HEAD–TO–TAIL

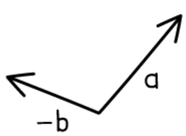


STEP 2: FORM THE RESULTANT VECTOR BY LINKING THE TAIL OF a TO THE HEAD OF −b

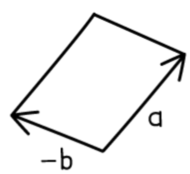


PARALLELOGRAM METHOD

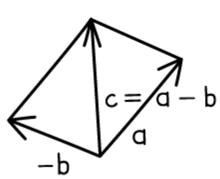
STEP 1: LINK THE VECTORS TAIL–TO–TAIL



STEP 2: COMPLETE THE RESULTING PARALLELOGRAM

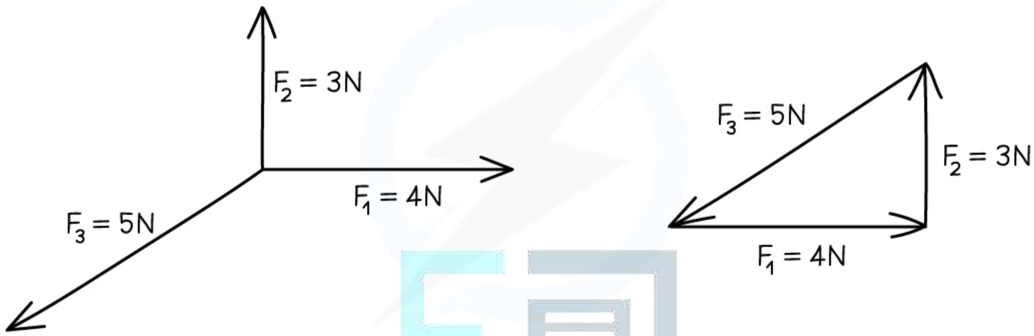


STEP 3: THE RESULTANT VECTOR IS THE DIAGONAL OF THE PARALLELOGRAM



Condition for Equilibrium

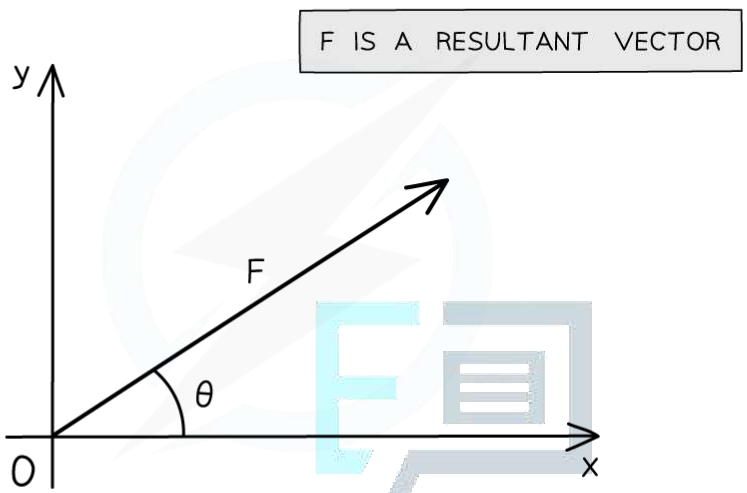
- Coplanar forces can be represented by vector triangles
- In equilibrium, these are **closed** vector triangles. The vectors, when joined together, form a closed path



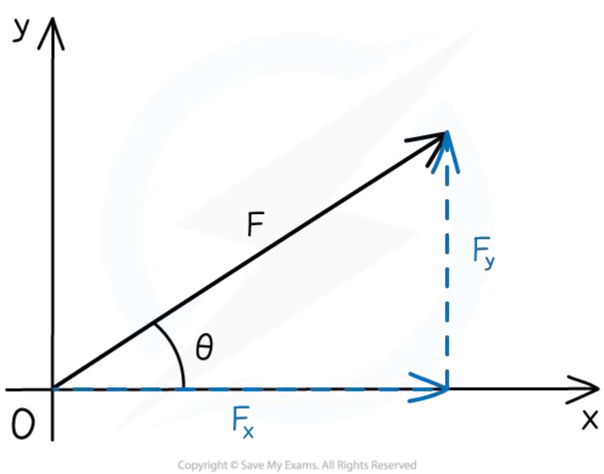
If three forces acting on an object are in equilibrium; they form a closed triangle

Resolving Vectors

- Two vectors can be represented by a single **resultant vector** that has the same effect
- A single resultant vector can be resolved and represented by **two** vectors, which in combination have the same effect as the original one
- When a single resultant vector is broken down into its **parts**, those **parts** are called components
- For example, a force vector of magnitude *F* and an angle of θ to the horizontal is shown below



- It is possible to **resolve** this vector into its **horizontal** and **vertical** components using trigonometry



- For the **horizontal component**, $F_x = F\cos\theta$
- For the **vertical component**, $F_y = F\sin\theta$

Random & Systematic Errors

- Measurements of quantities are made with the aim of finding the true value of that quantity
- In reality, it is impossible to obtain the true value of any quantity, there will always be a degree of uncertainty
- The uncertainty is an estimate of the difference between a measurement reading and the true value
- Random and systematic errors are two types of measurement errors which lead to uncertainty

Random error

- Random errors cause unpredictable fluctuations in an instrument's readings as a result of uncontrollable factors, such as environmental conditions
- This affects the **precision** of the measurements taken**,** causing a wider spread of results about the mean value
- To **reduce** random error: **repeat** measurements several times and calculate an average from them

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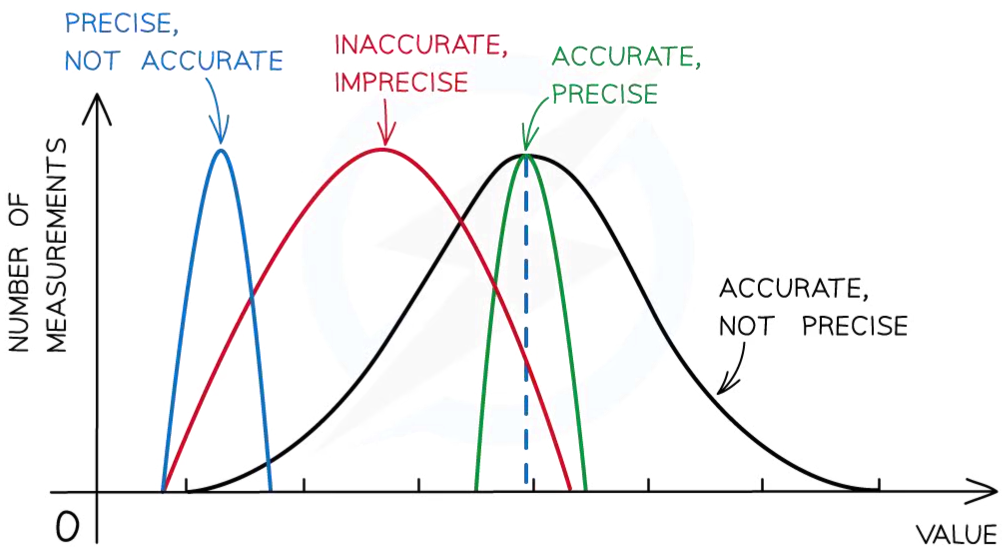
Systematic error

- Systematic errors arise from the use of faulty instruments used or from flaws in the experimental method
- This type of error is repeated every time the instrument is used or the method is followed, which affects the **accuracy** of all readings obtained
- To **reduce** systematic errors: instruments should be **recalibrated** or the technique being used should be corrected or adjusted



Representing precision and accuracy on a graph

Zero error

- This is a type of systematic error which occurs when an instrument gives a reading when the **true reading is zero**
- This introduces a fixed error into readings which must be accounted for when the results are recorded

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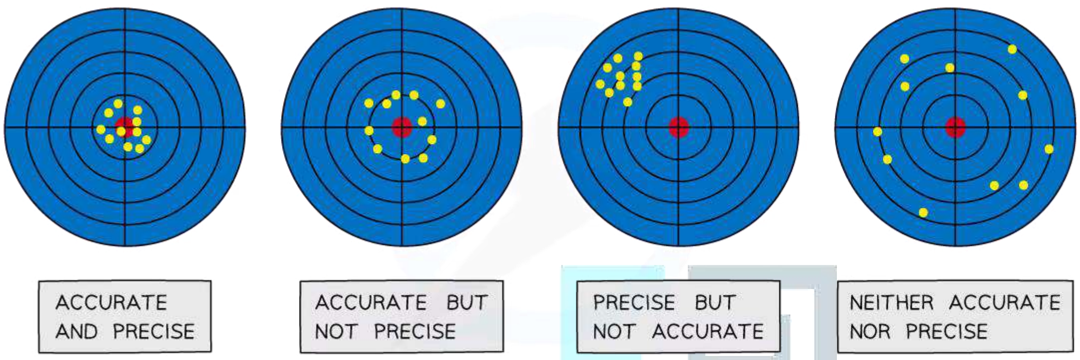
Precision & Accuracy

- **Precision of a measurement:** this is how close the measured values are to each other; if a measurement is repeated several times, then they can be described as precise when the values are very similar to, or the same as, each other
- The precision of a measurement is reflected in the values recorded – measurements to a greater number of decimal places are said to be more **precise** than those to a whole number
- **Accuracy**: this is how close a measured value is to the true value; the accuracy can be increased by repeating measurements and finding a mean average



The difference between precise and accurate results

Exam Tip

It is very common for students to confuse precision with accuracy – measurements can be precise but not accurate if each measurement reading has the same error. Precision refers to the ability to take multiple readings with an instrument that are close to each other, whereas accuracy is the closeness of those measurements to the true value.

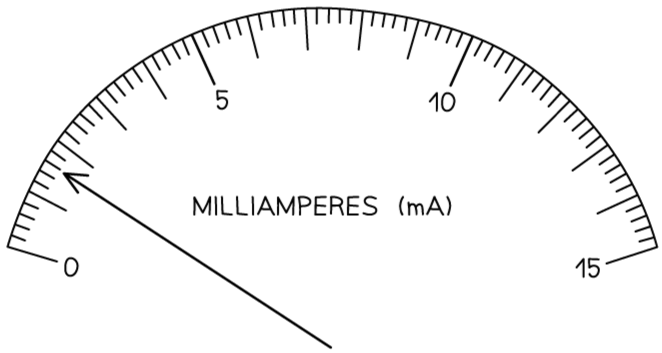
Calculating Uncertainty

- There is always a degree of uncertainty when measurements are taken; the uncertainty can be thought of as the difference between the **actual** reading taken (caused by the equipment or techniques used) and the **true value**
- Uncertainties are not the same as errors
  - Errors can be thought of as issues with equipment or methodology that cause a reading to be different from the true value
  - The uncertainty is a range of values around a measurement within which the true value is expected to lie, and is an **estimate**

- For example, if the true value of the mass of a box is 950 g, but a systematic error with a balance gives an actual reading of 952 g, the uncertainty is ±2 g
- These uncertainties can be represented in a number of ways:
  - **Absolute Uncertainty:** where uncertainty is given as a fixed quantity
  - **Fractional Uncertainty:** where uncertainty is given as a fraction of the measurement
  - **Percentage Uncertainty:** where uncertainty is given as a percentage of the measurement

$$percentage\ uncertainty = \frac{uncertainty}{measured\ value}\ x\ 100\%$$

- To find uncertainties in different situations:
- **The uncertainty in a reading:** ± half the smallest division
- **The uncertainty in a measurement:** at least ±1 smallest division
- **The uncertainty in repeated data:** half the range i.e. ± ½ (largest − smallest value)
- **The uncertainty in digital readings:** ± the last significant digit unless otherwise quoted



SMALLEST DIVISION = 0.2 mA

READING (I) = 1.6 mA

ABSOLUTE UNCERTAINTY $(\Delta I) = \frac{1}{2} \times 0.2 \text{ mA} = 0.1 \text{ mA}$

$I = 1.6 \pm 0.1 \text{ mA}$

FRACTIONAL UNCERTAINTY $= \frac{\text{UNCERTAINTY}}{\text{VALUE}} = \frac{0.1}{1.6} = \frac{1}{16}$

$I = 1.6 \pm \frac{1}{16} \text{ mA}$

PERCENTAGE UNCERTAINTY $(\%) = \frac{\text{UNCERTAINTY}}{\text{VALUE}} \times 100 = \frac{0.1}{1.6} \times 100 = 6.2\%$

$I = 1.6 \pm 6.2\% \text{ mA}$

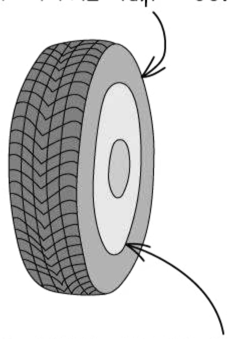
How to calculate absolute, fractional and percentage uncertainty

Combining Uncertainties

- The rules to follow
- Adding / subtracting data – add the absolute uncertainties

ADDING / SUBTRACTING DATA

DIAMETER OF TYRE (d_1) = 55.0 ± 0.5 cm



DIAMETER OF INNER TYRE (d_2) = 21.0 ± 0.7 cm

DIFFERENCE IN DIAMETERS ($d_1 - d_2$) = 55.0 − 21.0 = 34.0 cm

UNCERTAINTY IN DIFFERENCE = ±(0.5 + 0.7) = ± 1.2 cm

$d_1 - d_2$ = 34.0 ± 1.2 cm

- Multiplying / dividing data – add the percentage uncertainties

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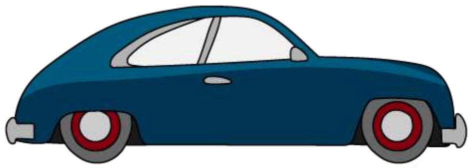
MULTIPLYING / DIVIDING DATA



DISTANCE = 50.0 ± 0.1 m

TIME = 5.00 ± 0.05 s

$$\text{SPEED } (v) = \frac{\text{DISTANCE } (s)}{\text{TIME } (t)}$$

$$V = \frac{50.0}{5.0} = 10.0 \text{ ms}^{-1}$$

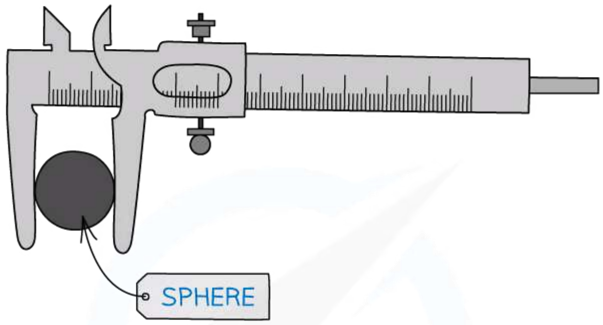
$$\frac{\Delta v}{v} = \frac{\Delta s}{s} + \frac{\Delta t}{t} = \frac{0.1}{50.0} + \frac{0.05}{5.00} = 0.002 + 0.01 = 0.012$$

ABSOLUTE UNCERTAINTY $(\Delta v) = 10.0 \times 0.012 = \pm 0.12 \text{ ms}^{-1}$

$v = 10.0 \pm 0.12 \text{ ms}^{-1}$

- Raising to a power – multiply the uncertainty by the power

RAISING TO A POWER



$V = \frac{4}{3}\pi r^3$

$r = 2.50 \pm 0.02$ cm

$V = \frac{4}{3}\pi(2.50)^3 = 65.5\ cm^3$

$\frac{\Delta V}{V} = 3 \times \frac{\Delta r}{r} = 3 \times \frac{0.02}{2.50} = 0.024$

ABSOLUTELY UNCERTAINTY $(\Delta V) = 65.5 \times 0.024 = 1.57 cm^3$

PERCENTAGE UNCERTAINTY $(\%\Delta V) = 100 \times 0.024 = 2.4\%$

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Measurement Techniques

- Common instruments used in Physics are:
  - Metre rules – to measure distance and length
  - Balances – to measure mass
  - Protractors – to measure angles
  - Stopwatches – to measure time
  - Ammeters – to measure current
  - Voltmeters – to measure potential difference
- More complicated instruments such as the micrometer screw gauge and Vernier calipers can be used to more accurately measure length

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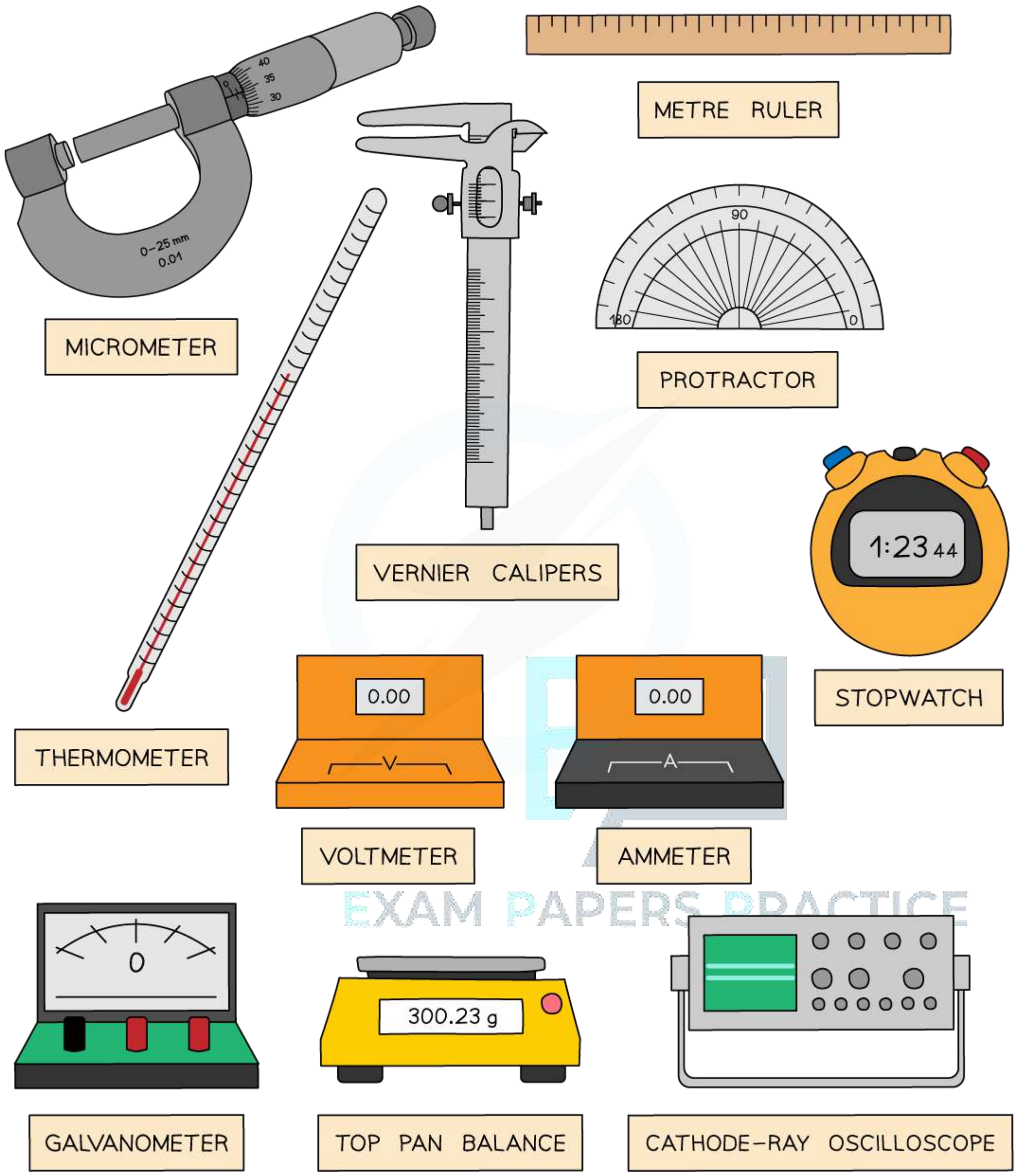

- When using measuring instruments like these you need to ensure that you are fully aware of what each division on a scale represents
    - This is known as the **resolution**

- The resolution is the smallest change in the physical quantity being measured that results in a change in the reading given by the measuring instrument
- The smaller the change that can be measured by the instrument, the greater the degree of resolution
- For example, a standard mercury thermometer has a resolution of 1°C whereas a typical digital thermometer will have a resolution of 0.1°C

- The digital thermometer has a higher resolution than the mercury thermometer

Measuring Instruments Table

Quantity	Instrument	Typical Resolution
Length	Metre rule	1 mm
Length	Vernier Calipers	0.05 mm
Length	Micrometer	0.001 mm
Mass	Top-pan Balance	0.01 g
Angle	Protractor	1°
Time	Stopwatch	0.01 s
Temperature	Thermometer	1 °C
Potential Difference	Voltmeter	1 mV – 0.1 V
Current	Ammeter	1 mA – 0.1 A

Micrometer Screw Gauge

- A micrometer, or a micrometer screw gauge, is a tool used for measuring small widths, thicknesses or diameters
  - For example, the diameter of a copper wire

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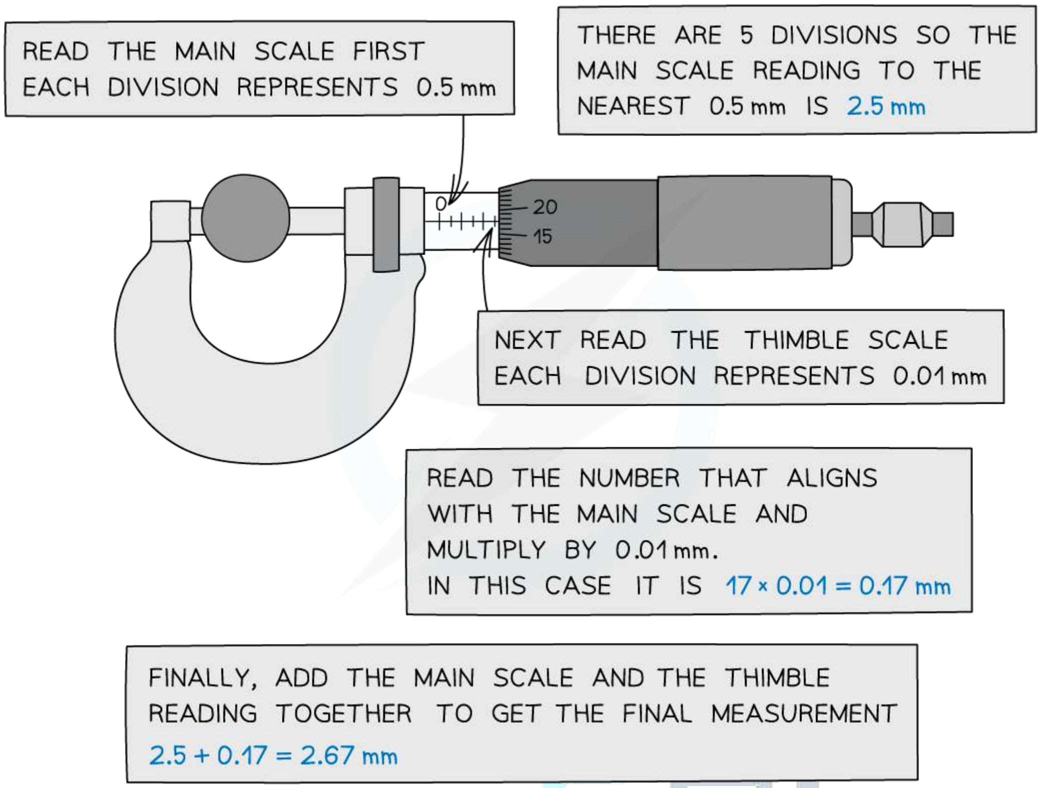
- It has a resolution of **0.01 mm**
- The micrometer is made up of two scales:
  - The main scale - this is on the sleeve (sometimes called the barrel)
  - The thimble scale - this is a rotating scale on the thimble
- The spindle and anvil are closed around the object being measured by rotating the ratchet
  - This should be tight enough so the object does not fall out but not so tight that is deformed
  - **Never** tighten the spindle using the **barrel**, only using the **ratchet**. This will reduce the chances of overtightening and zero errors
- The value measured from the micrometer is read where the thimble scale aligns with the main scale
  - This should always be recorded to 2 decimal places (eg. 1.40 mm not just 1.4 mm)

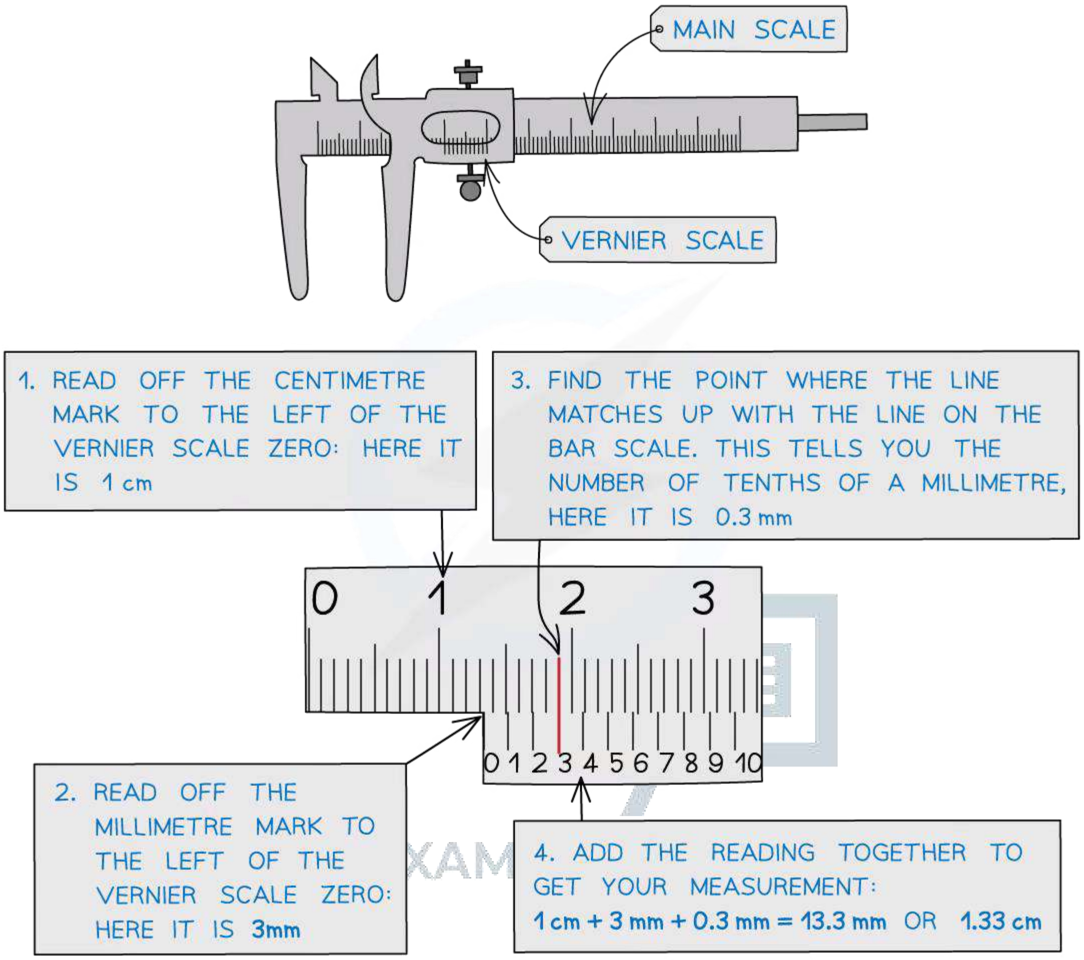


How to operate a micrometer

Vernier Calipers

- Vernier calipers are another distance measuring tool that uses a sliding vernier scale
  - They can also be used to measure diameters and thicknesses, just like the micrometer
  - However, they can also measure the length of small objects such as a screw or the depth of a hole
- Vernier calipers generally have a resolution of **0.1 mm**, however, some are as small as 0.02 mm – 0.05 mm
- The calipers are made up of two scales:
  - The main scale
  - The vernier scale
- The two upper or lower jaws are clamped around the object
  - The sliding vernier scale will follow this and can be held in place using the locking screw
- The value measured from the caliper is read when the vernier scale aligns with the main scale

- This should always be recorded to at least 1 decimal place (eg. 12.1 mm not just 12 mm)



The vernier caliper reading is read when the vernier scale aligns with the main scale