MEASUREMENTS AND ERRORS

Error and Uncertainities :-

Quantities are measured to find the exact (true) value of the quantity but its not possible to obtain the true value of any quantity, there will always be a degree of uncertanity.

is an estimate of the difference between a measured reading and the true value.

DON'T FORGET

Uncertainties are not same as errors :-

- Errors can be thought of as issues with equipment or methodology that causes a reading to be different from the true value.

- Wherelse uncertainity is a range of values within which the true value is expected to lie, and is an estimate

- For example, if the true value for the mass of box is 750g but due to systematic error with the balance, it reads 752 g, the uncertainty is ±2g.

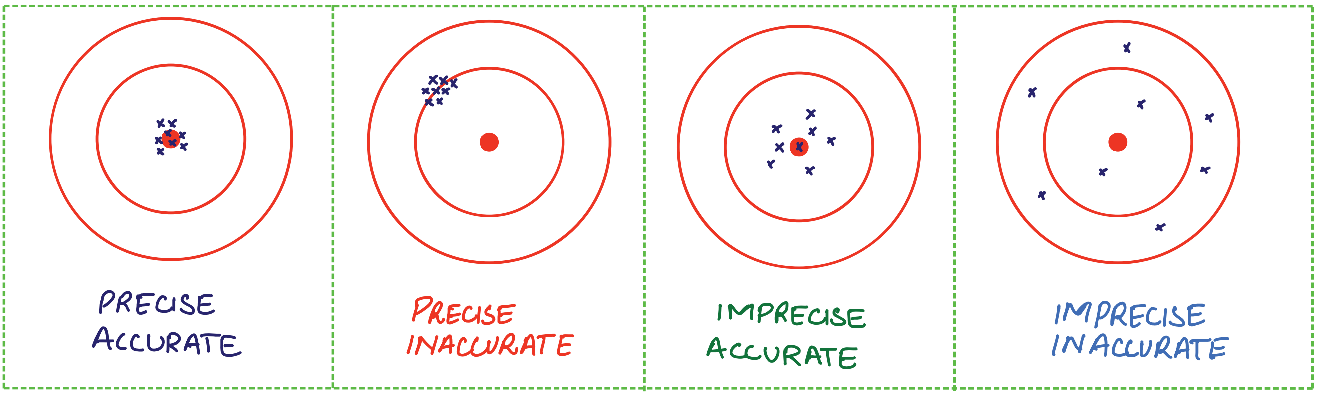
Precision and Accuracy :-

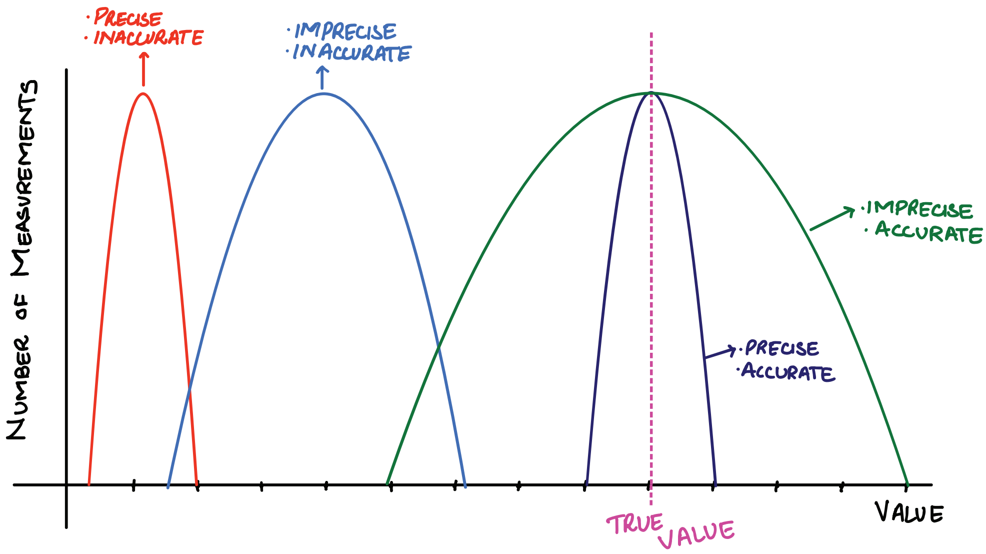
Precision:-

this is how close the measured values are to each other. If a measurement is repeated several time, it can be described as precise when the values are very similar to each other.

Accuracy :-

this is how close a measured is to the true value. The accuracy can be increased by repeating measurements and finding the average value.





➡ We have two types of measurement error which leads to uncertainity.

1) Random Error
2) Systematic Error

Random Error :-

causes unpredicted fluctuations in measurement as a result of uncontrollable factors such as environmental conditions, human error.

∴ This affects the precision of the measurements taken, causing a wider spread of results about the mean value

∴ These types of errors can be reduced by repeating measurements several times and calculate average.

Systematic Error :-

are caused due to fault in the instrument or from flaws in the experimental method.

∴ This error is repeated in every reading as the flaw is in instrument used hence it affects the accuracy of all readings obtained

∴ these types of error can be reduced by the recalibration of the instrument or the experimental method should be adjusted.

➡ Remember systematic error can't be reduced by taking average or mean

Uncertainties can be represented in different ways:-

➡ Absolute uncertainity :- (Δx)

where uncertainty is given as a fixed quantity.

➡ Fractional uncertainty :- $\left(\frac{\Delta x}{x}\right)$

where uncertainty is given as a fraction of the measurement.

➡ Percentage uncertainty :- $\left(\frac{\Delta x}{x} \times 100\right)$

where uncertainty is given as a percentage of the measurement.

EXAMPLE :-

Measurement $= 750 \pm 2$ g

➡ absolute uncertainity (Δm) ⟶ 2 g

➡ fractional uncertainty $\left(\frac{\Delta m}{m}\right)$ ⟶ $\frac{2}{750} = \frac{1}{375}$

➡ percentage uncertainty $\left(\frac{\Delta m}{m} \times 100\right)$ ⟶ $\frac{2}{750} \times 100 = 0.267\ \%$

Calculating Uncertainties in Different Situations :-

The uncertainty in a reading :-

± half the smallest division on the scale of instrument

The uncertainty in a measurement :-

atleast ± the smallest division on the scale of instrument

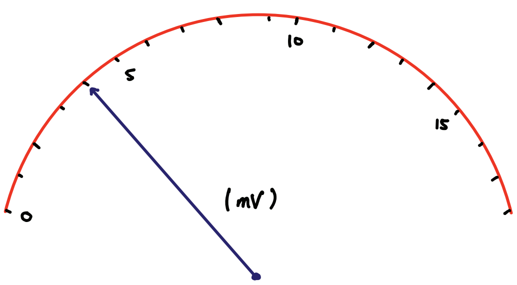
The uncertainty in repeated data :-

± half the range i.e. $\pm \frac{1}{2}$ (largest value − smallest value)

The uncertainty in digital readings :-

± the last significant digit unless otherwise quoted by the question or examiner.

EXAMPLE :-



∴ It s' a reading.

- The value shown here is : 4mV
- The smallest division on scale is : 1mV
- uncertainty is : $\frac{1}{2} \times 1mV = 0.5mV$
- reading = $\underline{4.0 \pm 0.5 \text{ mV}}$

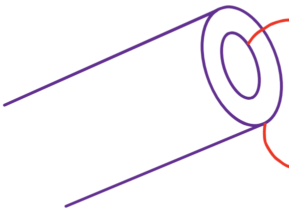
Combining Uncertainties :-

Adding / Subtracting data :-

(If data is being added or subtraced)

∴ in this case absolute uncertainties are added up.

EXAMPLE :-



* $d_o - d_i = 53.9 - 24.3$
$= 29.6 \text{ cm}$

* uncertainty in $d_o - d_i = 0.5 + 0.9$
$= 1.4 \text{ cm}$

$d_o - d_i = 29.6 \pm 1.4 \text{ cm}$

$$\text{thickness} = \frac{d_o - d_i}{2} = \frac{29.6 \pm 1.4}{2}$$

$$\boxed{\text{thickness} = 14.8 \pm 0.7 \text{ cm}}$$

Multiplying / Dividing Data :-

(If data is being multiplied or divided)

∴ In this case fractional / percentage uncertainties are added up, this gives the total fractional or percentage uncertainty.

EXAMPLE mass = 3.4 ± 0.1 kg

volume = 0.40 ± 0.05 m^3

ρ = ?

$$\rho = \frac{m}{V} = \frac{3.4}{0.4} = 8.5 \text{ kgm}^{-3}$$

total fractional uncertainty in density = fractional uncertainty in mass + fractional uncertainty in volume

$$\frac{\Delta \rho}{\rho} = \frac{\Delta m}{m} + \frac{\Delta V}{V}$$

$$\frac{\Delta \rho}{\rho} = \frac{0.1}{3.4} + \frac{0.05}{0.4}$$

$$\frac{\Delta \rho}{\rho} = \frac{21}{136}$$

$$\frac{\text{absolute uncertainty in density}}{\text{density}} = \frac{21}{136}$$

$$\frac{\Delta \rho}{8.5} = \frac{21}{136}$$

$$\Delta \rho = 1.3125 \text{ kgm}^{-3}$$

$\rho = 8.50 \pm 1.3125 \text{ kgm}^{-3}$

$\boxed{\text{density} = 9 \pm 1 \text{ kgm}^{-3}}$

Raising to a power :-

In this case we will multiply the fractional or percentage uncertainty by the power, this will give total fractional or percentage uncertainty.

EXAMPLE

Radius of sphere = 2.70 ± 0.03 cm

Volume = ?

* $V = \frac{4}{3}\pi r^3$ * $V = \frac{4}{3}\pi(2.7)^3$ * $V = 82.45\ cm^3$

fractional uncertainty in V

$$\frac{\Delta V}{V} = \frac{\Delta r}{r} \times 3$$

$$= \frac{0.03}{2.7} \times 3$$

$$\frac{\Delta V}{V} = \frac{1}{30}$$

absolute uncertainty (ΔV) = $\frac{1}{30} \times V$

$$\Delta V = \frac{1}{30} \times 82.45$$

$$\Delta V = 2.75\ cm^3$$

$V = 82.45 \pm 2.75\ cm^3$

volume = $82 \pm 3\ cm^3$

Measurement Techniques :-

In physics we have different physical quantities and to measure these quantities different instruments are used.

Common instruments used in physics are :-

- Meter rule → to measure length
- Balances → to measure mass
- Protractors → to measure angle
- Stopwatch → to measure time
- Ammeter → to measure current
- Voltmeter → to measure potential difference
- Thermometer → to measure temperature

When using measuring instruments like these you need to ensure that you are fully aware of what each division on scale represents, this is known as resolution (least count).

Micrometer Screwguage :-

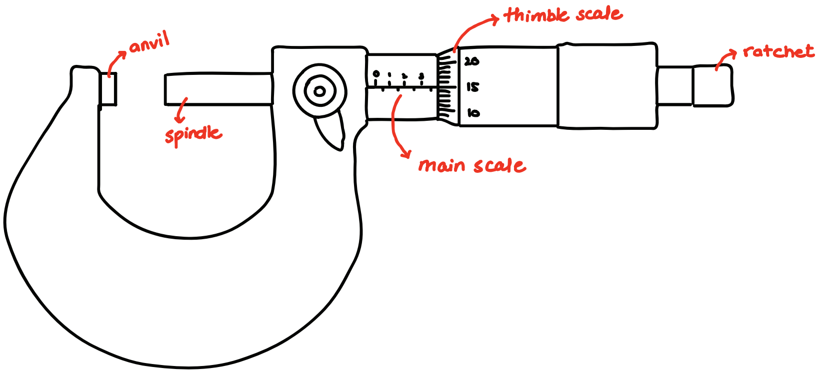
An instrument used for measuring small lengths such as diameter of wires.

∴ It has a resolution of 0.01 mm.

∴ It measures the length upto 25 mm. (2.5 cm)

∴ The micrometer is made up of two scales:

- The Main Scale → this is on the sleeve.
- The Thimble Scale → this is the rotating scale on thimble.



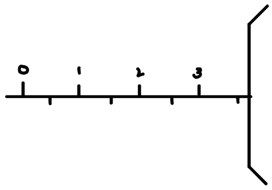
∴ The spindle and anvil are closed around the object being measured by rotating the ratchet, this should be tight enough so the object does not fall out but not so tight that object deforms.

∴ Never tighten the spindle using barrel (thimble), only use ratchet for tightening. This will reduce the chances of overtightening and zero errors.

∴ Micrometer only measures the outer diameter, we cannot measure inner diameter using micrometer.

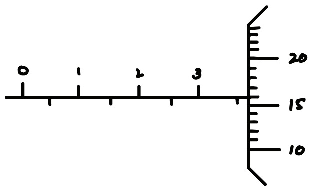
How to read micrometer :-

- Read the main scale first, each division on top reprsents 1mm and bottom divisions represent 0.5mm.



∴ The largest reading visible on main scale is main scale reading = 3.5 mm

- Next, read the thimble scale, there are 50 divisions on the thimble scale. Read the number on thimble scale that aligns with the main scale and multiply it with the resolution (0.01 mm)



∴ Thimble scale reads 16, multiply it with 0.01 mm $16 \times 0.01 = 0.16\,mm$

- Finally, add the main scale reading and the thimble scale reading together to get the final measurement.

final reading = main scale reading + thimble scale reading

final reading = 3.5 mm + 0.16 mm

final reading = 3.66 mm

Vernier Caliper :-

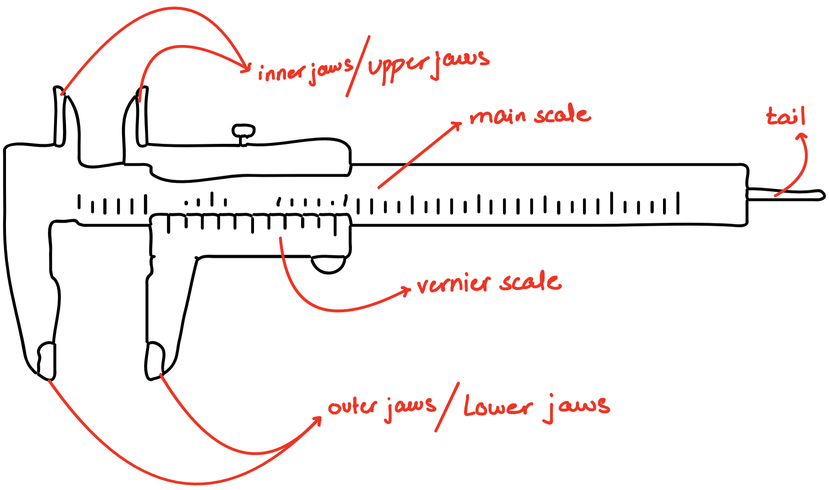
Another distance measuring instrument that uses a sliding vernier scale.

∴ Generally, it has resolution of 0.1 mm.

∴ It measures the length upto 15 cm.

∴ The calipers are made up of two scales :-

- The Main Scale :-
- The Vernier Scale :-

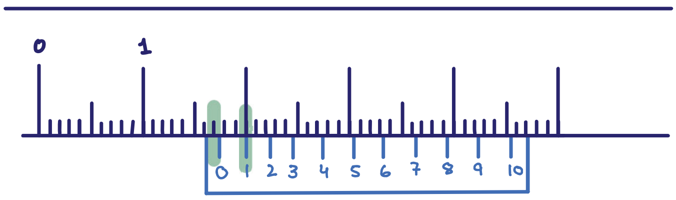


∴ The two upper or lower jaws are clamped around the object, the sliding vernier scale will follow this and can be held in place using the locking screw.

∴ Vernier Calipers can measure inner and outer diameter using upper and lower jaws respectively. The tail of calipers can be used to measure depth.

⇒ How to read vernier caliper :-

- Read off reading on main scale to the left of the vernier scale zero. (1.7 cm)
  This reading is main scale reading.



- Find the point on vernier scale where the line matches up with the line on main scale (1)
  multiply it with the resolution ($1 \times 0.1mm = 0.1mm$)
  This is known as vernier scale reading.

- Finally, add the main scale reading and the vernier scale reading together to get the final measurement.

∴ Remember to make units same for both scales before adding :-

main scale reading = 1.7 cm = 17 mm

vernier scale reading = 1×0.01 = 0.1 mm

final reading = main scale reading + vernier scale reading

final reading = 17 mm + 0.1 mm

final reading = 17.1 mm OR 1.71 cm

Additional Information :-

Zero Errors :-

this is a type of systematic error which occurs when 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.

Measurement and reading are not same :-

Measurement	Reading
∴ zero errors (lining up with zero)	∴ No zero errors (no lining up with zero)
∴ uncertainty = (resolution)	∴ uncertainty = $\frac{1}{2}$ (resolution)
∴ Examples	∴ Examples
· meter rule	· thermometer
· protractor	· measuring cylinder
· micrometer / vernier calliper	