Measurements and Experimentation

Need of Unit for Measurement

- **Measurement** is the process of comparison of the given physical quantity with the known standard quantity of the same nature.
- A **unit** is the quantity of a constant magnitude which is used to measure the magnitudes of other quantities of the same nature.
- The magnitude of a physical quantity is expressed as
  $\text{Physical quantity} = (\text{numerical value}) \times (\text{unit})$
- A unit can be chosen if it has appropriate properties.

Kinds of Units

- Fundamental or basic unit: A fundamental unit is that which is independent of any other unit or which can neither be changed nor be related to any other fundamental unit.
- Derived units: Derived units are those which depend on the fundamental units or which can be expressed in terms of the fundamental units.

Examples of Derived Units

Quantity	Definition	Derived unit	Symbol
Area	length × breadth	metre × metre	m^2
Work or energy	force × displacement	$\text{kilogram} \times \frac{\text{metre}}{\text{second}^2} \times \text{metre} = \text{joule}$	$kg\ m^2\ s^{-2}$ = J
Pressure	$\frac{\text{force}}{\text{area}}$	$\frac{\text{kilogram} \times \text{metre}}{\text{second}^2} / (\text{metre})^2 = \frac{\text{newton}}{(\text{metre})^2} = \text{pascal}$	$kg\ m^{-1}\ s^{-2}$ = N m^{-2} = Pa
Resistance	$\frac{\text{potential}}{\text{current}}$	$\frac{\text{kilogram}(\text{metre})^2}{\text{ampere} \times \text{second}^3} / \text{ampere} = \frac{\text{volt}}{\text{ampere}} = \text{ohm}$	$kg\ m^2\ A^{-2}\ s^{-3}$ = V A^{-1} = Ω

Systems of Units

- There are three systems of units used worldwide. They are CGS, FPS and MKS.
  - CGS system or French system: The unit of length is centimetre, the unit of mass is gram and the unit of time is second.
  - FPS system or British system: The unit of length is foot, the unit of mass is pound and the unit of time is second.
  - MKS system or Metric system: The unit of length is metre, the unit of mass is kilogram and the unit of time is second.

- **Systeme Internationale d'unites or SI system**
  According to this system, there are nine fundamental units, including two angular units.

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	Kelvin	K
Luminous intensity	candela	cd
Electric current	ampere	A
Amount of substance	mole	mol
Angle	radia	rd
Solid angle	steradian	st-rd

- For expressing large or small numbers/amounts, prefixes are used.

Units of Length

- The SI unit of length is metre (m).
- A metre is defined as the distance which light travels in $\frac{1}{299,792,458}$ of a second in air or vacuum.

Sub-units of Metre

- Centimetre, millimetre, micrometre or micron and nanometre.

Non-metric Units of Length

- **Bigger Units**
  - Astronomical unit (AU): One astronomical unit is equal to the mean distance between the Earth and the Sun.
    $1\,\text{A.U} = 1.496 \times 10^{11}\ \text{m} \approx 1.5 \times 10^{11}\ \text{m}$
  - Light year (ly): A light year is the distance travelled by light in vacuum in one year.
    $1\,\text{ly} = 9.46 \times 10^{12}\ \text{km}$
  - Parsec: One parsec is the distance from where the semi-major axis of the orbit of the Earth subtends an angle of 1" (one second) at the centre of the Sun. One parsec is 3.26 light years.
    $1\,\text{parsec} = 3.08 \times 10^{16}\ \text{m}$

- **Smaller Units**
  - Angstrom ($\overset{0}{\text{A}}$): $1\ \overset{0}{\text{A}} = 10^{-10}\ \text{m} = 10^{-8}\ \text{cm} = 10^{-9}\ \text{nm}$
  - fermi (f): $1\,\text{f} = 10^{-15}\ \text{m}$

Units of Mass

- The SI unit of mass is kilogram (kg).
- One kilogram is defined as the mass of a cylindrical piece of platinum–iridium alloy kept in International Bureau of Weights and Measures at Sevres near Paris.

The **sub-units of kilogram** are gram (g) and milligram (mg).

The **non-metric unit of mass** is atomic mass unit (amu) or the unified atomic mass unit (u).

$1\,\text{a.m.u} = \frac{1}{12}$ th the mass of one carbon-12 atom

Units of Time

- The SI unit of time is second (s).
- A second is defined as $\frac{1}{86,400}$ th part of a mean solar day.

  $1\,\text{s} = \frac{1}{86400} \times$ one mean solar day
- In 1964, one second was defined as the time interval of 9,192,631,770 periods of a specified energy change in the cesium-133 atom.

Common Units of Time

- Minute (min), Hour (h), Day, Month, Lunar month, Year, Leap year, Decade, Century and Millennium.

Guidelines for Writing Units

- The symbol of a unit, which is not named after a scientist, is written in lower case.
- The symbol of a unit, which is named after a scientist, is written with the first letter of his name in capital.
- The full name of a unit, even when it is named after a scientist, is written with a lower initial letter.
- A compound unit formed by multiplication of two or more units is written after putting a dot, cross or leaving a space in between the two symbols.
- A negative power is used for compound units, which are formed by dividing one unit by the other.
- A unit in its short form is never written in plural.

Least Count of a Measuring Instrument

- The least count of an instrument is the smallest measurement which can be taken accurately with it.
- The least count of an instrument is the value of the smallest division on its scale.
- Smaller the least count of an instrument, the more accurate the measurement

Measurement of Length with a Metre Scale

- A metre scale is a scale with length one metre which is graduated in cm and has subdivisions in mm. There are 10 subdivisions in each cm.
- The value of one small division on the metre scale is 1 mm. Thus, its least count is 1 mm.
- Precautions should be taken while measuring the length of an object.
- The limitation of a metre scale is that it can measure the length correctly up to one decimal place of a centimetre.

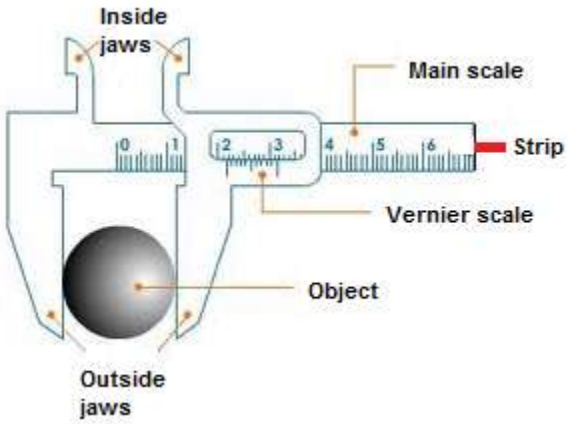
Principle of Vernier

- Two scales are used in this technique. One is the **main scale**, and the other is called the **vernier scale**.
- The least count of vernier is equal to the difference between the values of one main scale division and one vernier scale division. This is called the **vernier constant**.
- 'n' divisions of vernier are equal to n−1 divisions of the main scale. Therefore, the value of one division of vernier $= \frac{(n-1)x}{n}$.

$$\text{L.C.} = \frac{\text{Value of 1 main scale division}(x)}{\text{Total number of divisions on vernier}(n)}$$

Vernier Callipers

- A vernier calliper is also called a slide calliper.



- The main parts of vernier callipers and their functions are given below.

Part	Function
Inside jaws	To measure the internal diameter of a hollow cylinder or pipe.
Outside jaws	To measure the length of a rod, the diameter of a sphere and the external diameter of a hollow cylinder.
Main scale	To measure the length correct up to 1 mm.
Vernier scale	To measure the length correct up to 0.1 mm.
Strip	To measure the depth of a beaker or a bottle.

- The least count of a vernier calliper is given as

$$\text{L.C.} = \frac{\text{Value of 1 main scale division}\,(x)}{\text{Total number of divisions on vernier}\,(n)}$$

- **Zero error in vernier callipers:** The **zero error** is equal to the distance between the zero of the main scale and the zero of the vernier scale.

- **Kinds of zero error**
- There are two kinds of zero error—positive and negative zero error.
  - Positive zero error: When the zero mark of the vernier scale is on the right of the zero mark of the main scale, the zero error is said to be positive.
  - Negative zero error: When the zero mark of the vernier scale is on the left of the zero mark of the main scale, the zero error is said to be negative.
- The correction due to zero error, that is, the correct measure of the length is

$$\text{Correct reading} = \text{Observed reading} - \text{Zero error}$$

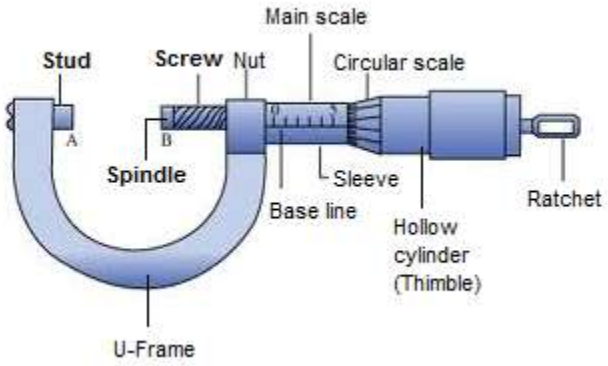
- Positive zero error gets subtracted and negative zero error gets added to the observed reading.

Principle of Screw

- The **pitch** of the screw is the distance moved by the screw along its axis in one complete rotation of its head.
- There are graduations along the circumference of the head of the screw. There are 50–100 graduations. This is called the circular scale or head scale.
- The pitch of the screw is 1 mm. If there are 100 divisions on the circular scale, then the **least count** of the screw is 1/100 = 0.01 mm = 0.001 cm.
- The least count of a screw is the distance moved by it in rotating the circular scale by one division.

$$\text{L.C.} = \frac{\text{Pitch of screw}}{\text{Total number of divisions on circular scale}}$$

Screw Gauge



- The main parts of a screw gauge and their functions are given below.

Part	Function
Circular scale	To read length correct up to 0.01 mm.
Main scale	To read length correct up to 1 mm.
Sleeve	To mark the main scale and the base line.
Thimble	To mark the circular scale.
Ratchet	To advance the screw by turning it till the object is gently held between the stud and the spindle of the screw.

- **Pitch and Least Count**

  The pitch of a screw gauge is the linear distance moved by its screw on the main scale when the circular scale completes one full rotation.

  The least count is the linear distance moved by its screw on the main scale when the circular scale is rotated by one division.

$$\text{L.C.} = \frac{\text{Pitch of screw}}{\text{Total number of divisions on circular scale}}$$

- **Kinds of zero error**
- There are two kinds of zero error—positive and negative zero error.
  - Positive zero error: When the zero mark of the circular scale is below the base line of the main scale, the zero error is said to be positive.
  - Negative zero error: When the zero mark of the circular scale is above the base line of the main scale, the zero error is said to be negative.

- The correction due to zero error, that is, the correct measure of the length is

$$\text{Correct reading} = \text{Observed reading} - \text{Zero error}$$

- **Backlash error**

  Due to wear and tear of the threads of the screw, it is observed that on reversing the direction of rotation of the thimble, the tip of the screw does not start moving in the opposite direction at once, but it remains stationary for some part of rotation. The error caused due to this effect is called **backlash error**.