CHAPTER

01

Measurements & Experimentation

SYLLABUS

• International System of Units. • Other commonly used system of units FPS and CGS. • Measurements using common instruments. • Vernier calliper and micrometer screw gauge for length and simple pendulum for time.

The word Physics is derived from the Greek word Physica which means nature, so physics is the branch of science concerned with the nature and laws governing it. Under the physics, we study interaction between different physical quantities along with their measurement.

Physical Quantities

All the quantities which can be measured directly or indirectly are called physical quantities. Physical quantities can be further divided into two types i.e. **fundamental** and **derived quantities.**

Fundamental Quantities

The physical quantities which are independent of other physical quantities and are not defined in terms of other physical quantities are called **fundamental** or **base quantities.** e.g. Mass, length, time, temperature, luminous intensity, electric current and amount of substance are the seven fundamental quantities. Besides these seven fundamental quantities, there are two more physical quantities known as **supplementary quantities,** these are plane angle and solid angle.

Derived Quantities

The physical quantities which can be derived from the fundamental physical quantities are called **derived quantities.** e.g. Velocity, acceleration, linear momentum, etc. All physical quantities other than the seven base quantities are derived quantities.

Measurement of Physical Quantities

The measurement of a physical quantity is the process of comparing the given quantity with a standard amount of the physical quantity of same kind, called its **unit**.

Hence, to express the measurement of a physical quantity, we need to know two parameters as given below

(i) The **unit** in which the quantity is measured.

(ii) The **numerical value** of the quantity, i.e. the number of times that unit is contained in the given physical quantity.
Thus, the magnitude of the physical quantity is expressed as
Physical quantity = Numerical value × Unit

$$\boxed{Q = nu}$$

e.g. Mass of an object can be expressed as 2 kg.

Physical Units

The standard amount of a physical quantity chosen to measure the physical quantity of same kind is called a physical unit.

As we know, unit is to be measured universally, so it should be valid everywhere.

Hence, the essential requirements of physical unit are as follows

(i) It should be of suitable size.

(ii) It should be easily accessible.

(iii) It should not vary with time.

(iv) It should be easily reproducible.

(v) It should not depend on physical conditions like pressure, volume, temperature, etc.

The unit is classified into two kinds-**fundamental units** and **derived units.**

Fundamental Units

Those physical units which can neither be derived from another unit nor be further resolved into more simpler units are called fundamental units.

The units of fundamental quantities like length, mass, time, temperature, electric current and amount of substance are called **fundamental units** or **base units.**

Derived Units

The units of measurement of all other physical quantities which can be derived from fundamental units are called derived units.

e.g. The unit of speed is derived from the units of two fundamental units length and time as given below

$$\boxed{\text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{\text{m}}{\text{s}} = \text{ms}^{-1}}$$

Systems of Units

In mechanics, there are three fundamental quantities length, mass and time. Different systems used for units of these three basic quantities are discussed below

(i) **The FPS System** It is the British engineering system of units. It uses foot as the unit of length, pound as the unit of mass and second as the unit of time.

(ii) **The CGS System** It is based on Gaussian system of units which uses centimetre, gram and second for length, mass and time, respectively.

(iii) **The MKS System** It uses metre, kilogram and second as the fundamental units of length, mass and time, respectively.

(iv) **The International System of Units** (SI Units) The system of units which is accepted internationally for measurement is the system of International Units (French for International System of Units) abbreviated as SI.

Now, the SI system of unit is used which is a modified version of other three metric systems.

International System of Units (SI Units)

The SI with standard scheme of symbols, units and abbreviations was developed and recommended by **General Conference on Weights and Measures** in 1960 for international usage in scientific, technical, industrial and commercial work.

This system consists of seven fundamental units and two supplementary units which are abbreviated as shown in table below

Base Quantities and their SI Units

Base Quantity	SI Units Name	SI Units Symbol	Definition
Length	Metre	m	One metre is the length of the path travelled by light in vacuum during a time interval of 1/299792458 a second established in the year 1983.
Mass	Kilogram	kg	One kilogram is equal to the mass of the international prototype of the kilogram (a platinum-iridium alloy cylinder) kept at International Bureau of weights and measures, at Sevres, near Paris, France in the year 1889.
Time	Second	s	One second is the duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom in the year 1967.
Electric current	Ampere	A	One ampere is that constant current which, if maintained in two straight parallel conductors of infinite length of negligible circular cross-section and placed 1m apart in vacuum, would produce between these conductors, a force equal to 2×10^{-7} Nm^{-1} of length in the year 1948.
Thermodynamic temperature	Kelvin	K	One kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water established in the year 1967.
Amount of substance	Mole	mol	One mole is the amount of substance of system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12 established in the year 1971.
Luminous intensity	Candela	cd	One candela is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of (1/683) W/Sr established in the year 1979.

Supplementary Quantities and their SI Units

Supplementary Quantity	Units	Symbol
Plane angle	Radian	rad
Solid angle	Steradian	Sr

Some Examples of Derived SI Units Expressed in Terms of Base Units

Derived Quantity	Definition	Derived Units	Symbol
Area	Length × Breadth	Metre × Metre	m^2
Volume	Length × Breadth × Height	Metre × Metre × Metre	m^3
Density	$\frac{\text{Mass}}{\text{Volume}}$	$\frac{\text{Kilogram}}{(\text{Metre})^3}$	$kg\text{-}m^{-3}$
Speed/Velocity	$\frac{\text{Distance}}{\text{Time}}$	$\frac{\text{Metre}}{\text{Second}}$	ms^{-1}
Acceleration	$\frac{\text{Velocity}}{\text{Time}}$	$\frac{\text{Metre/Second}}{\text{Second}}$	ms^{-2}
Force	Mass × Acceleration	$\text{Kilogram}\times\frac{\text{Metre}}{(\text{Second})^2}$	$kg\text{-}ms^{-2}$ or N
Momentum	Mass × Velocity	$\text{Kilogram}\times\frac{\text{Metre}}{\text{Second}}$	$kg\text{-}ms^{-1}$ or N-s
Work/Energy	Force × Displacement	$\text{Kilogram}\times\frac{\text{Metre}\times\text{Metre}}{(\text{Second})^2}$	$kg\text{-}m^2\,s^{-2}$ or J
Power	$\frac{\text{Work}}{\text{Time}}$	$\text{Kilogram}\times\frac{(\text{Metre})^2}{(\text{Second})^2}$ / Second	$kg\text{-}m^2\,s^{-3}$ or Js^{-1} or W
Electric charge	Current × Time	Ampere × Second	A-s or C

Some prefixes used for different measurements

Prefix	Symbol	Value
Femto	f	10^{-15}
Pico	p	10^{-12}
Nano	n	10^{-9}
Micro	µ	10^{-6}
Milli	m	10^{-3}
Centi	c	10^{-2}
Deci	d	10^{-1}
Deca	da	10^{1}
Hecto	h	10^{2}
Kilo	k	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}

e.g. 1 megaohm (MΩ) = $10^6 \Omega$

1 milliampere (mA) = 10^{-3} A

Note Advantage of SI over other unit of measurement

(i) It is easily reproducible

(ii) It has unique unit for each physical quantity.

(iii) SI is internationally accepted.

Some Important Practical Units for Length/Distance

Sub-units of metre

(i) **Centimetre (cm)** 1 cm = 10^{-2} m

(ii) **Millimetre (mm)** 1 mm = 10^{-3} m

(iii) **Micron or Micrometre** 1 µm = 10^{-6} m

(iv) **Nanometre (nm)** 1 nm = 10^{-9} m

Multiple units of metre

Kilometre (km) 1 km = 10^3 m

Non-metric unit of length

Bigger units

(i) **Astronomical Unit** It is the mean distance of the earth from the sun.

$$1 \text{ AU} = 1.496 \times 10^{11} \text{ m}$$

(ii) **Light Year** It is the distance travelled by light in vacuum in one year.

$$1 \text{ ly} = 9.46 \times 10^{15} \text{ m}$$

(iii) **Parallactic Second** It is the distance at which an arc of length 1 astronomical unit subtends an angle of 1s of arc.

$$1 \text{ parsec} = 3.084 \times 10^{16} \text{m} = 3.26 \text{ ly}$$

Smaller units

(i) **Angstrom Unit** This unit is used for inter-atomic and intermolecular separation.

$$1\text{Å} = 10^{-10}\text{m} = 10^{-1}\text{nm}$$

(ii) **Fermi** This unit is used for measuring nuclear sizes.

$$1 \text{ fm} = 10^{-15} \text{ m}$$

Some Important Units for Mass

Sub-units of kilogram

(i) **Gram (g)** 1 g = 10^{-3} kg

(ii) **Milligram (mg)** = 10^{-6} kg

Multiple units of kilogram

(i) **Quintal (q)** 1q = 100 kg

(ii) **Metric tonne (t)** 1t = 1000 kg

Non-metric unit of mass

Bigger unit

Solar mass (M) $1\text{M} = 2 \times 10^{30}$ kg

Smaller unit

1 amu (u) $1\,u = 1.66 \times 10^{-27}$ kg

Some Important Units of Time

Bigger units

(i) **Minute (min)** One minute is the duration of 60 s. i.e. 1 min = 60 s

(ii) **Hour (h)** One hour is the duration of 60 min. i.e. 1 h = 60 min = 3600 s

(iii) **Day** The time taken by the earth to rotate once on its own axis is called a day. One day is divided in 24 h.

Thus, 1 day = 24 h = 24 × 60 × 60 = 86400 s.

(iv) **Lunar month** A lunar month is of 29.5 days and 12 lunar months are of 354.37 days.

(v) **Month** One month is considered to be of 30 days (approx) and one year 12 months or 365 days.

(vi) **Year (yr)** One year is defined as the time in which the earth completes one revolution around the sun. i.e. 1 yr = 365 days

$$1 \text{ yr} = 365 \times 86400 = 3.1536 \times 10^7 \text{ s}$$

(vii) **Leap year** A leap year is considered as the year in which the month of February is of 29 days.

1 leap year = 366 days.

(viii) **Decade** One decade has 10 years.

$$1 \text{ decade} = 3.1536 \times 10^8 \text{ s}$$

(ix) **Century** One century has 100 years.

1 century = 3.16×10^9 s

(x) **Millennium** One millennium has 1000 years.

1 millennium = 3.16×10^{10} s

Smaller units

(i) **Millisecond (ms)** 1 ms = 10^{-3} s

(ii) **Microsecond (μs)** 1 μs = 10^{-6} s

(iii) **1 shake** = 10^{-8} s

(iv) **Nanosecond (ns)** 1 ns = 10^{-9} s

Rules for Writing SI Units

(i) Small letters are used for symbols of units. e.g. The symbol of metre is m, the symbol of kilogram is kg.

(ii) Symbols do not take plural form. e.g. 30 kilograms in short form is 30 kg and 200 kilometres in short form is 200 km.

(iii) The initial letter of a symbol is taken in capital letter when the unit is named after a scientist. e.g. The symbol of unit of force (newton) is N, the symbol of unit of energy (joule) is J and the symbol of unit of power (watt) is W.

(iv) The full name of a unit always begins with a small letter even if it has been named after a scientist. e.g. Unit of force is newton not 'Newton', unit of energy is 'joule' not Joule, unit of power is 'watt' not Watt.

Some General Units (Outside from SI)

Name	Symbol	Value in SI Unit
degree	°	$1° = (\pi/180)$ rad
litre	L	1 $dm^3 = 10^{-3}$ m^3
carat	c	200 mg
bar	bar	0.1 MPa = 10^5 Pa
curie	Ci	3.7×10^{10} s^{-1}
roentgen	R	2.58×10^{-4} C/kg
barn	b	100 $fm^2 = 10^{-28}$ m^2
area	a	1 $dam^2 = 10^2$ m^2
hectare	ha	1 $hm^2 = 10^4$ m^2
standard atmospheric pressure	atm	101325 Pa $= 1.013 \times 10^5$ Pa

Example 1. Write the derived unit for pressure.

Sol. $\because$ Pressure $= \frac{\text{Force}}{\text{Area}} = \frac{\text{Mass} \times \text{Acceleration}}{\text{Area}}$

Substituting the units of mass, acceleration and area in the above expression, we get

Unit of pressure $= \frac{\text{kg} \times \text{ms}^{-2}}{\text{m}^2} = \text{kgm}^{-1}\text{s}^{-2}$

Unit Conversion

The process of changing unit from one system to other system of unit is called **unit conversion.**

Example 2. The acceleration due to gravity is 9.8 ms^{-2}. Give its value in ft s^{-2}.

Sol. As, 1m = 3.28 ft

$\therefore$ $9.8 \text{ ms}^{-2} = 9.8 \times 3.28 \text{ ft s}^{-2}$

$= 32.14 \text{ ft s}^{-2} \approx 32 \text{ ft s}^{-2}$

Example 3. The value of gravitational constant G in MKS system is 6.67×10^{-11} N-m^2 kg^{-2}. What will be its value in CGS?

Sol. Given, $G = 6.67 \times 10^{-11}$ N-m^2 kg^{-2}

$= 6.67 \times 10^{-11} (\text{kg-ms}^{-2}) \text{m}^2 \text{kg}^{-2}$

$= 6.67 \times 10^{-11} (\text{m}^3)(\text{s}^{-2})(\text{kg}^{-1})$

$= 6.67 \times 10^{-11} (100 \text{cm})^3 (\text{s})^{-2} (10^3 \text{ g})^{-1}$

$= 6.67 \times 10^{-8} \text{ cm}^3 \text{ g}^{-1} \text{ s}^{-2}$

Example 4. Calculate the number of light years in one metre.

Sol. We know that, 1 ly = 9.46×10^{15} m

or 9.46×10^{15} m = 1 ly

$\therefore$ $1 \text{ m} = \frac{1}{9.46 \times 10^{15}}$

$= 1.057 \times 10^{-16}$ ly

Example 5. Deduce relation between astronomical unit, light year and parsec. Arrange them in decreasing order of their magnitudes.

Sol. We know that, 1 AU = 1.496×10^{11} m

1 ly = 9.46×10^{15} m

1 parsec = 3.084×10^{16} m

$\therefore$ $\frac{1 \text{ ly}}{1 \text{ AU}} = \frac{9.46 \times 10^{15}}{1.496 \times 10^{11}} = 6.3 \times 10^4$

1 ly = 6.3×10^4 AU

Now, conversion of light year into parsec.

i.e. $\frac{1 \text{ parsec}}{1 \text{ ly}} = \frac{3.084 \times 10^{16}}{9.46 \times 10^{15}} = 3.26$

$\therefore$ 1 parsec = 3.26 ly

On comparing above results, we get

1 parsec > 1 ly > 1 AU

Check Your LEARNING...

1 What are the two types of physical quantities?
2 Write the name of two supplementary physical quantities.
3 Give any one advantage of SI unit over other systems of unit.
4 Convert 10 m/s to km/s. *Ans.* 0.01 km/s
5 Which one is largest, astronomical unit, light year or parsec?

Measurement of Length

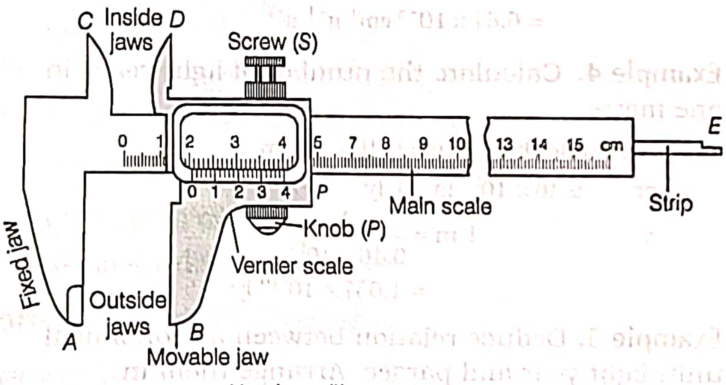
Length is the distance of separation between two points in space. There are many instruments used to measure length like meter scale, inch tape, etc. Here, we will discuss two instruments vernier calliper and screw gauge, which are used to measure very small lengths.

Vernier Calliper

Vernier calliper is a device used to measure accurately upto $\left(\frac{1}{10}\right)$th of a millimetre. It was designed by a **French Mathematician Pierre Vernier**, hence the instrument is named so.

Construction of Vernier Calliper

Vernier calliper consists of following parts



Vernier calliper and its parts

(i) **Main Scale** It is divided into division of different magnitude. The main scale is a fixed one that looks like a rectangular flat steel bar which is graduated in cm and mm. It consists of two fixed jaws *C* and *A* at right angles to the scale.

(ii) **Vernier Scale** It is also divided into division of different magnitude. This scale slides over the main scale. With the help of screw *S*, the vernier scale can be fixed at the desired position and the knob *P* is used to slide the vernier scale. The vernier scale is graduated with 10 divisions over a length of 9 mm i.e. 9 main scale divisions are equal to 10 vernier scale divisions.

(iii) **Movable Jaws** The vernier scale consists of two movable jaws *B* and *D* projecting at right angles to the scale. When the jaws of the main scale and the vernier scale touch each other, then the zero mark on the vernier scale coincides with the zero mark on the main scale, i.e. the instrument is free from zero error. The inside jaws *C* and *D* are used to measure the **internal diameter** of an object and the fixed jaw *A* and movable jaw *B* are used to measure the **external diameter** of the object.

(iv) **Metallic Strip** The thin metallic strip *E* provided at the end of the main scale is connected with vernier scale. When the two jaws *A* and *B* are in contact with each other, the strip *E* touches the edge of main scale and when the jaws *A* and *B* are separated, then the metallic strip *E* moves outward. It is used to measure the depth of a vessel.

Principle of Vernier Calliper

As, mentioned in vernier calliper construction, 10 divisions of vernier scale coincide with 9 divisions of main scale.

∴ 10 VSD (Vernier Scale Division)

= 9 MSD (Main Scale Division)

$$\therefore \quad 1 \text{ VSD} = \frac{9}{10} \text{ MSD}$$

$$1 \text{ VSD} = \frac{9}{10} \text{ mm} \qquad (\because 1 \text{ MSD} = 1 \text{ mm})$$

Thus, the difference between one main scale division and one vernier scale division is 1 mm − 0.9 mm = 0.1 mm.

This illustrates that vernier calliper can measure length accurately upto 0.1 mm.

Least Count (LC) of Vernier Calliper

The minimum measurement that vernier calliper can take is called its least count.

The least count of vernier calliper is equal to the difference between the values of one main scale division and one vernier scale division. It is also called the **vernier constant.**

Let the value of one of the smallest division on the main scale be x and y be that on vernier scale. So, when the fixed and the movable jaws get joined, then

$$(n-1) \text{ MSD} = n \text{VSD}$$

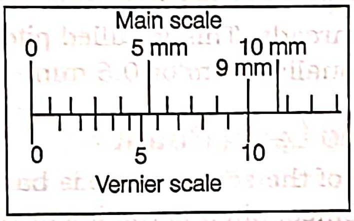
i.e $(n-1) \times$ divisions of main scale $= n \times$ divisions on vernier scale

$$(n-1)x = ny$$
$$\Rightarrow \quad (x-y)n = x$$
$$\Rightarrow \quad (x-y) = \frac{x}{n}$$

Therefore, Least Count (LC)
$$= \frac{\text{Value of one of the smallest division on main scale}}{\text{Total number of small divisions on the vernier scale}}$$

Determination of Zero Error

If the instrument is perfect, the zero mark of the vernier scale should coincide with the zero mark of the main scale, when the jaws C and D are made to touch each other.

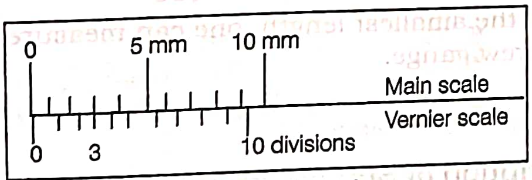


In such a situation, the instrument is free from any error.

However, in actual practice, due to wear and tear of the jaws and some manufacturing defects, zero error rises.

Zero error can be of two types

(i) **Positive Zero Error** When the zero mark of the vernier scale lies towards the right side of the zero of the main scale, when jaws C and D are made to touch each other. Then the zero error is called positive zero error. In such a situation, the measured length will be more than the actual length. It is because of this fact that the zero error is called positive zero error.

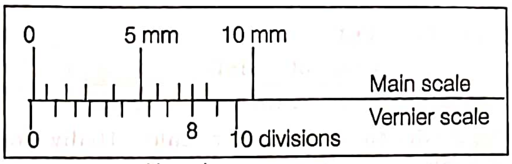


Positive zero error

Zero error $= (+)3 \times LC = +3 \times 0.01$ cm $= +0.03$ cm

(ii) **Negative Zero Error** When the zero mark of the vernier scale lies towards the left side of the zero of the main scale, when jaws C and D are in contact with each other, the zero error is called negative zero error.

The length of an object measured by this instrument will be less than the actual length of the object. It is because of this reason that the zero error is called negative zero error.



Negative zero error

Zero error $= (-)\,(0.01 \times 8)$ cm
$= -0.08$ cm

Measurement of Length of an Object by Vernier Calliper

The following steps are involved in measurement of length of an object with a vernier calliper

(i) First of all join both the jaws A and B of vernier calliper together.

(ii) Find the least count and zero error (if any) of the vernier calliper.

(iii) Move the jaw B away from the jaw A and place the object between the jaws.

(iv) Now, move the jaw B towards A till it touches the object and then tighten the screw S to fix the vernier scale in this position.

(v) Note the reading on main scale (MSR).

(vi) Note that division N on vernier scale which coincides with any division on main scale.

(vii) Use the formula, observed length $= \text{MSR} + (N \times \text{LC})$.

(viii) Now, introduce the zero error correction (if any), i.e.

Correct reading = Observed reading − Zero error

True length = Observed length − Zero error (with sign)

Example 6. In an instrument, there are 25 divisions on the vernier scale which have length of 24 divisions of the main scale. 1 cm on main scale is divided in 25 equal parts. Find the least count.

Sol. The value of one main scale division, $x = \frac{1}{25}$ cm

The number of divisions on vernier scale, $n = 25$

$\therefore$ LC of vernier

$$= \frac{\text{Value of one main scale division } (x)}{\text{Number of divisions on vernier scale } (n)}$$

$$= \frac{(1/25)}{25} = \frac{1}{625} = 0.0016 \text{ cm}$$

Example 7. A vernier calliper has 1mm mark on the main scale. It has 20 equal divisions on the vernier scale which matches with 16 main scale divisions. For this vernier calliper, calculate the least count.

Sol. Least count of a vernier calliper,

$$LC = 1\,MSD - 1\,VSD$$

$$= \frac{\text{Value of 1 MSD}}{\text{Total divisions on the vernier scale}}$$

Since, 20 divisions of vernier scale = 16 divisions of main scale

$$\Rightarrow \quad 1\,VSD = \frac{16}{20}\,mm = 0.8\,mm \qquad (\because 1\,MSD = 1\,mm)$$

$$\therefore \quad LC = 1\,MSD - 1\,VSD$$

$$= 1\,mm - 0.8\,mm = 0.2\,mm$$

Screw Gauge

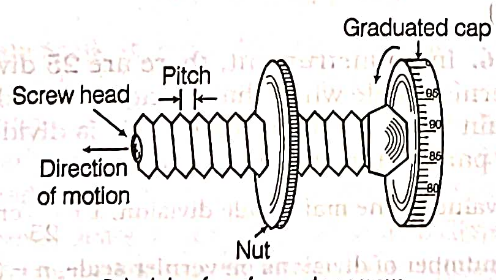
With the help of vernier calliper, we can measure the length accurately upto 0.1 mm but screw gauge is more precise and accurate measuring instrument of length upto 0.01 mm or 0.005 mm. Thus, a screw gauge is an instrument of higher precision than a vernier calliper.

It is an instrument used for measuring very small lengths such as diameters of wires which cannot be accurately measured by vernier calliper. It is because the least count of screw gauge is smaller than the least count of a vernier calliper. A screw gauge works on the principle of a micrometer screw.

Micrometer Screw

A micrometer screw is shown in figure. There are evenly spaced threads on the screw. It means that the separation between two consecutive threads is same.

The screw can be moved forward and backward in a closely fitting nut also comprising evenly spaced threads.

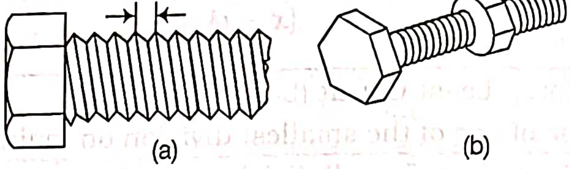


Principle of a micrometer screw

There are two types of motions associated with the micrometer screw

(i) Linear motion (ii) Circular motion

Pitch of Screw



A screw (a) without nut (b) with nut

In an ordinary screw (as shown in above figures), the separation between any two consecutive threads is same, it can be moved backward and forward in its nut by rotating it anti-clockwise or clockwise. During one complete rotation, distance travelled by the screw is equal to the separation between two consecutive threads. This is called **pitch (*P*)** of the screw. It is usually 1 mm or 0.5 mm.

Principle and Least Count

The principle of the screw gauge is based on the least count. Since, pitch is the linear distance travelled by screw in one complete rotation of its head and least count of screw gauge is the ratio of pitch to the total number of divisions on the circular scale.

Therefore, pitch

$$= \frac{\text{distance moved by the screw}}{\text{number of rotations given to the screw}}$$

and least count

$$= \frac{\text{pitch of the screw}}{\text{number of divisions on circular scale}}$$

e.g. For a screw gauge with a pitch of 1 mm and 100 divisions on the circular scale,

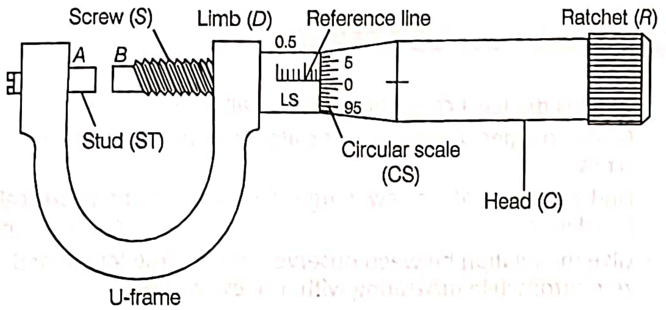
$$\text{Least count} = \frac{1\text{ mm}}{100} = 0.01\text{ mm}$$

This is the smallest length, one can measure with this screw gauge.

Note The screw gauge having a least count of 0.001 mm or 10^{-6} m is called micrometer screw.

Description of Screw Gauge

The figure given below is a screw gauge. It consists of a screw *S* which advances forward or backward as one rotates the head *C* through ratchet *R* in clockwise or anti-clockwise direction. It also consists of a Linear Scale (LS) attached to limb *D* of the U-frame.



Screw gauge

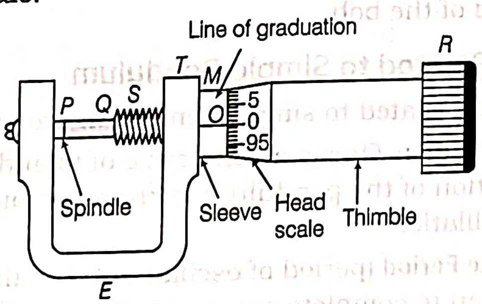
The smallest division on the linear scale is 1 mm. There is a Circular Scale (CS) on the head, which can be rotated. A line parallel to the axis of screw is inscribed on the body of the screw, this line is called **reference line**. There are 100 divisions on the circular scale.

There are two studs A and B in the screw gauge. They serve as two jaws of the screw gauge. The stud A is fixed with the U-frame while stud B as the flat end of the screw is movable which can move forward and backward.

When the end B of the screw touches the surface A of the stud (ST), the zero marks on the main scale and the circular scale should coincide with each other. When both the studs touch each other or they come in contact, the ratchet itself turns on to loose the control over the screw. This in turn helps to avoid the undue pressure over the object placed between the studs.

Determination of Zero Error

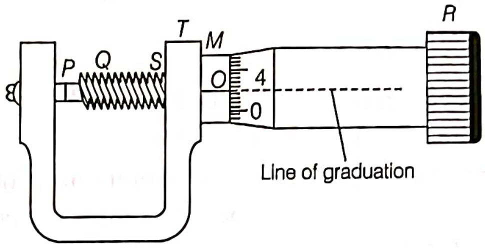
In a perfect instrument, when the gap between P and Q is reduced to zero, the zero of the head scale will lie along the line of graduation and the edge of the head scale lies exactly in front of the zero of the pitch scale.



Zero error

In case, this is not so, then the instrument is said to possess an error called **zero error**. Like the zero error of vernier calliper, the zero error in case of screw gauge may also be positive or negative.

(i) **Positive Zero Error** In this case, the zero of the circular scale is below the line of graduation as the gap between P and Q is reduced to zero. Since, the zero of the circular scale lies to the right hand side of the zero of the pitch scale, the error is called positive zero error.



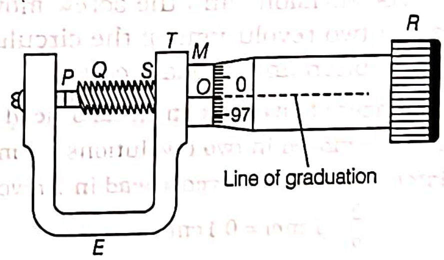
Let us determine the magnitude of this error by taking an example.

e.g. Refer the given figure (above), in which the zero line of the head scale is 4 divisions below the line of graduation.

$\therefore$ Zero error $= +4 \times \text{LC} = +4 \times 0.01 = +0.04$ mm

(ii) **Negative Zero Error** In such a case, the zero of the circular scale lies above the line of graduation, when the gap between P and Q is reduced to zero.

Under this condition, the edge of the circular scale lies to the left hand side or above the zero of the pitch scale. This is why, the zero error is called negative zero error.



Let us determine the magnitude of this error with the help of an example.

e.g. Refer the given figure (above), Zero line on circular scale is 3 divisions (out of 100) above from line of graduation. This shows that error is negative.

$\therefore$ Zero error $= -3 \times \text{LC}$

$= -3 \times 0.01$ mm

$= -0.03$ mm

Backlash Error

When the screw is rotated very fast to measure a reading, then there is some slipping between the different tip of screw and thimble due to wear and tear or due to a loose fitting of threads which gives an incorrect reading of threads.

It is observed that on reversing the direction of rotation of thimble in screw gauge, the tip of screw remains stationary, i.e. it does not start moving in the opposite direction at once. The error due to this in observation is called backlash error.

Measurement with a Screw Gauge

The following steps are involved during measurement with a screw gauge

(i) Very first step is to find out least count of given screw gauge. (Remember it should be about 0.01 mm)

(ii) Check out, whether the screw gauge has any zero error or not. (Write it properly, along with sign)

(iii) Place the object between P and Q and turn the ratchet in clockwise direction till ratchet becomes free.

(iv) Note down the Main Scale Reading (MSR) and number of circular divisions coincide with base line called Circular Scale Reading (CSR).

(v) Observed diameter = MSR + CSR × LC

(vi) True diameter = Observed diameter − Zero error (with sign).

Example 8. The circular head of a screw gauge is divided into 100 divisions and the screw moves 2 mm ahead in two revolutions of the circular head. Calculate its (i) pitch and (ii) least count.

Sol. Given, number of divisions on circular head = 100 and distance moved in two revolutions = 2 mm

(i) ∴ Pitch = Distance moved ahead in 1 revolution

$$= \frac{2}{2} = 1 \text{ mm} = 0.1 \text{cm}$$

(ii) $\therefore \text{Least count} = \dfrac{\text{Pitch}}{\text{Number of divisions on circular head}}$

$$LC = \frac{01}{100} = 0.001 \text{cm}$$

Example 9. A screw gauge gives the following reading, when used to measure the diameter of a wire. Main scale reading : 0 mm, Circular scale reading : 52 divisions. Given that, 1 mm on main scale corresponds to 100 divisions of the circular scale, then find the diameter of the wire.

Sol. Diameter of wire = MSR + CSR × LC

Given, Main Scale Reading (MSR) = 0 mm

Circular scale reading = 52 divisions

$$\therefore \text{Least Count (LC)} = \frac{\text{Value of 1 main scale division}}{\text{Total divisions on circular scale}} = \frac{1}{100}$$

$$\therefore \text{Diameter of wire} = 0 + 52 \times \frac{1}{100} = 0.52 \text{ mm} = 0.052 \text{ cm}$$

Check Your LEARNING...

1 What is the least count of a vernier calliper?

2 Give two types of motion associated with the micrometer screw.

3 Find zero error of a screw gauge, if zero line of the head scale is 5 divisions. *Ans.* + 0.05 mm

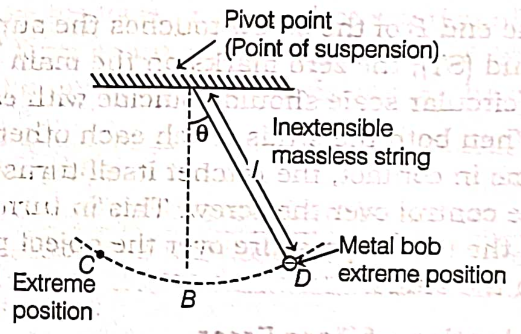
4 Give the relation between observed length, true length and zero error while measuring with a screw gauge.

Measurement of Time

In home and offices, we commonly use a pendulum clock to note time which depends upon time period of oscillation of a simple pendulum.

Simple Pendulum

A heavy object (bob), suspended from a rigid support, by an inextensible and light string set to oscillate freely due to gravity is called a simple pendulum.



Simple pendulum

In the given diagram, B is the mean position of the pendulum bob. If bob is shifted to D from B and then released, it comes in a motion known as oscillatory motion. C and D are the extreme positions of the bob.

Terms Related to Simple Pendulum

The terms related to simple pendulum are as follows

(i) **Oscillation** One complete cycle of to and fro motion of the pendulum is known as one oscillation.

(ii) **Time Period** (period of oscillation) The time taken to complete one oscillation is called time period. It is denoted by T and its SI unit is second (s).

(iii) **Frequency of Oscillation** The number of oscillations in one second is known as frequency of oscillation. It is denoted by (f) and its SI unit is hertz (Hz).

As, $f = \frac{1}{T}$

$$1 \text{ hertz} = (1 \text{ second})^{-1}$$

$$1 \text{ Hz} = 1 \text{s}^{-1}$$

(iv) **Amplitude** It is defined as the maximum displacement of simple pendulum from its mean position. It is denoted by A and its SI unit is metre (m).

(v) **Effective Length of a Pendulum** It is a distance between the point of oscillation (i.e., centre of gravity of the bob) from the point of suspension.

It is denoted by l and its SI unit is metre (m).

Relation between l and T

Length of a pendulum (l) and its time period (T) are related to each other by the given relation $T = 2\pi\sqrt{\frac{l}{g}}$

where, g is acceleration due to gravity.

Factors on which Period of Oscillation (T) Depends

The period of oscillation depends on the following factors

(i) Length of a Pendulum (l)

As,

$$T = 2\pi\sqrt{\frac{l}{g}}, \quad T \propto \sqrt{l}$$

Thus, if the length of a pendulum is more, then greater will be the time period and *vice- versa.*

e.g. Suppose we have a simple pendulum which takes 4 s to complete one oscillation. i.e. $T = 4$ s.

Now, if we increase its length by four times, then time period will be doubled. It means, now a pendulum will take 8 s to complete one oscillation.

(ii) Acceleration due to Gravity

As, $T = 2\pi\sqrt{\frac{l}{g}}$, thus $T \propto \frac{1}{\sqrt{g}}$

i.e. Time period is inversely proportional to square root of the acceleration due to gravity. Thus, from this relation, we find that, if the acceleration due to gravity is more, then smaller will be the time period and *vice-versa*.

Measurement of Time Period of a Simple Pendulum

To measure the time period of a simple pendulum, procedure is followed as given below

(i) The bob is slightly displaced from its mean position and then released. This sets the bob into vibrations.

(ii) Now, measure the time for 20 oscillations with the help of stopwatch.

(iii) Calculate the time period of pendulum by dividing the time of 20 oscillations by 20.

(iv) The experiment is then repeated for different lengths of the pendulum and the observations are recorded in a table as given below

Length	Time for 20 oscillations	Time period
25	20	1.0
36	24	1.2
49	28	1.4
64	32	1.6

From this table, it is observed that time period of simple pendulum is directly proportional to the square root of effective length of pendulum.

Graph between Effective Length and Time Period

(i) l versus T^2

As, $T = 2\pi\sqrt{\frac{l}{g}}$

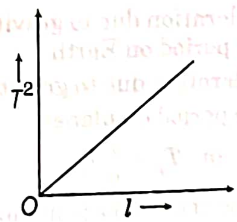
On squaring both sides, we get

$$T^2 = 4\pi^2\frac{l}{g} \Rightarrow T^2 = \left(\frac{4\pi^2}{g}\right) l$$

$\therefore \quad T^2 \propto l$

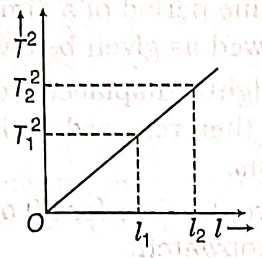
It shows that l varies linearly with T^2.

Hence, graph between l and T^2 will be a straight line starting from origin as shown below



Slope of T^2 versus l Graph The slope of T^2 *versus* l graph is constant at a given place and is given by

$$\text{Slope} = \frac{T_1^2 - T_2^2}{l_1 - l_2} = \frac{4\pi^2}{g}$$

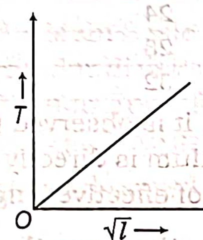


where, T_1 is the time period of the pendulum corresponding to the length l_1 and similarly, T_2 is the time period corresponding to length l_2.

(ii) $\sqrt{l}$ *versus* T

As, $T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow T = \left(\frac{2\pi}{\sqrt{g}}\right)\sqrt{l}$

$\therefore \quad T \propto \sqrt{l}$



Thus, this will be a straight line starting from origin.

Example 10. Suppose we have a simple pendulum of length l. It has a time period of 4 s on Earth (provided g on Earth is 10 ms^{-2} approx). What will be the time period of a simple pendulum on any planet which has $g = 40$ ms^{-2}?

Sol. As, l is same.

Thus, $T \propto \frac{1}{\sqrt{g}}$

Given, $g_e = 10\ \text{ms}^{-2}$, $g_p = 40\text{ms}^{-2}$, $T_e = 4$ s and $T_p = ?$

$\therefore \quad \frac{T_e}{T_p} = \sqrt{\frac{g_p}{g_e}} \Rightarrow \frac{T_e}{T_p} = \sqrt{\frac{40}{10}} \Rightarrow \frac{T_e}{T_p} = 2$

where, g_e = acceleration due to gravity on Earth,
T_e = time period on Earth,
g_p = acceleration due to gravity on planet
and T_p = time period on planet.

Thus, $T_e = 2T_p$ or $T_p = \frac{1}{2}T_e$

Hence, time period of a simple pendulum on planet will be $\frac{1}{2}T_e$.

$\therefore \quad T_p = \frac{4}{2} = 2$ s

Example 11. Find the length of a simple pendulum whose time period of oscillation is 2.8 s. (Take, $g = 9.8$ ms^{-2})

Sol. Given, time period of a pendulum, $T = 2.8$ s

Acceleration due to gravity, $g = 9.8$ ms^{-2}

We know that, $T = 2\pi\sqrt{\frac{l}{g}}$

$\Rightarrow \quad l = \frac{T^2 g}{4\pi^2} = \frac{(2.8)^2 \times 9.8}{4 \times (3.14)^2} = 1.94$ m

So, length of a simple pendulum = 1.94 m

Example 12. The length of a pendulum is decreased by 5%. What effect does it have on the time period of a pendulum?

Sol. Let the length of a pendulum be l.

i.e. $l_1 = l,\ l_2 = l - 5\%$ of $l = l - \frac{5}{100} \times l = 0.95l$

We know that, time period, $T \propto \sqrt{l}$

$\therefore \quad \frac{T_2}{T_1} = \frac{\sqrt{l_2}}{\sqrt{l_1}} = \sqrt{\frac{0.95 l_1}{l_1}} \Rightarrow \frac{T_2}{T_1} = \sqrt{0.95} = 0.97$

$T_2 = 0.97T_1 = (1 - 0.03)T_1 = T_1 - 0.03T_1$

i.e. $\quad T_2 = T_1 - 3\%\ T_1$

So, the time period will decrease by 3%, if length is decreased by 5%.

Second's Pendulum

A pendulum which has a time period of 2 s is known as second's pendulum.

$\Rightarrow \quad T = 2$s

It is used in clocks.

Example 13. What is the effective length of a second's pendulum?

Sol. Time period of a second's pendulum is 2 s.

As, $T = 2\pi\sqrt{\frac{l}{g}} \Rightarrow l = \frac{1}{4\pi^2}gT^2$

$l = \frac{1}{4\pi^2} \times 9.8 \times (2)^2 \quad (\because g = 9.8\ \text{ms}^{-2})$

$= \frac{1}{4 \times \left(\frac{22}{7}\right)^2} \times 9.8 \times 4 \quad \left(\because \pi = \frac{22}{7}\right)$

$= 0.99\ \text{m} \simeq 1\text{m}$

$\therefore$ The effective length of a second's pendulum is about 1 m (Taking, $g = 9.8$ ms^{-2}).

Check Your LEARNING...

1. Give the cause of motion of bob of a simple pendulum.
2. Define the amplitude of a simple pendulum.
3. If the length of a simple pendulum is increased, how will its time period vary?
4. If a simple pendulum is taken to the mars, how will its time period vary?
5. If the length of a simple pendulum is increased by 25%, then what is the change in its time period? *Ans.* 12.5% increase
6. Define a second's pendulum.

QUiCK Revision

- **Physical Quantities** All the quantities which can be measured directly or indirectly in terms of which laws of Physics are described and whose measurement is necessary.
- **Units of Physical Quantities** It is the standard amount of a physical quantity chosen to measure the physical quantity of same kind.
- **Fundamental Quantities and Units** The physical quantities which are independent of other physical quantities are called fundamental quantities and their units are called fundamental units.
- **Derived Quantities and Units** The physical quantities which can be derived from the fundamental quantities are called derived quantities and their units are called derived units.
- **The FPS System of Units** It is British engineering system of units and stands for foot, pound and second.
- **The CGS System of Units** It stands for centimetre, gram and second.
- **The MKS System of Units** It stands for metre, kilogram and second.
- **The SI System of Units** This system of units is internationally accepted form of measurement.
- **Meter Scale** It is used to measure length and its least count is 1 mm.
- **Vernier Calliper** This instrument is used to measure length accurately upto (1/10)th of a millimetre. Its least count is 0.01 cm and pitch is 0.1 cm. Also, 1 VSD (Vernier Scale Division) = 0.9 MSD (Main Scale Division).
- **Screw Gauge** This instrument is used to measure very small lengths which cannot be measured by vernier calliper. Its least count is given by

  $$\text{Least count} = \frac{\text{Pitch of the screw}}{\text{Total number of divisions on circular scale}}$$
- **Zero Error (i) For Vernier Calliper** On bringing the jaws of vernier calliper in contact with each other, the zero of the vernier scale in some instruments does not fall in line with the zero of the main scale. Such vernier callipers are said to possess zero error.
  (ii) For Screw Gauge When the gap between the two ends of the screw of a screw gauge is reduced to zero but the zero of the head scale does not lie along the line of graduation and the edge of the head scale, then such screw gauges are said to possess zero error.
- On the basis of direction of deviation of instruments from zero mark on their scale, zero errors are classified into two types i.e. **positive zero error** and **negative zero error.**
- **Simple Pendulum** This instrument is used to measure time. Time period of a simple pendulum is given by $T = 2\pi\sqrt{\frac{l}{g}}$, where l is the length of the pendulum and g is the acceleration due to gravity.