CHAPTER 3

Units, Dimension, Measurements and Practical Physics

Fundamental or base quantities

The quantities which do not depend upon other quantities for their complete definition are known as *fundamental or base quantities*.

e.g. : length, mass, time, etc.

Derived quantities

The quantities which can be expressed in terms of the fundamental quantities are known as *derived quantities*.

e.g. Speed (=distance/time), volume, acceleration, force, pressure, etc.

Units of physical quantities

The chosen reference standard of measurement in multiples of which, a physical quantity is expressed is called the *unit* of that quantity.

e.g. Physical Quantity = Numerical Value ×Unit

Systems of Units

	MKS	CGS	FPS	MKSQ	MKSA
(i)	Length (m)	Length (cm)	Length (ft)	Length (m)	Length (m)
(ii)	Mass (kg)	Mass (g)	Mass (pound)	Mass (kg)	Mass (kg)
(iii)	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)
(iv)	–	–	–	Charge (Q)	Current (A)

Fundamental Quantities in S.I. System and their units

S.N.	Physical Qty.	Name of Unit	Symbol
1	Mass	kilogram	kg
2	Length	meter	m
3	Time	second	s
4	Temperature	kelvin	K
5	Luminous intensity	candela	Cd
6	Electric current	ampere	A
7	Amount of substance	mole	mol

SI Base Quantities and Units

Base Quantity	SI Units		
	Name	Symbol	Definition
Length	meter	m	The meter is the length of the path traveled by light in vacuum during a time interval of 1/(299, 792, 458) of a second (1983)
Mass	kilogram	kg	The 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. (1889)
Time	second	s	The second is the duration of 9, 192, 631, 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom (1967)
Electric Current	ampere	A	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per metre of length. (1948)
Thermodynamic Temperature	kelvin	K	The kelvin, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (1967)
Amount of Substance	mole	mol	The mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. (1971)
Luminous Intensity	candela	Cd	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian (1979).

Note :- On November 16, 2018 at the General Conference on Weights and Measure (GCWM) the 130 years old definition of kilogram was changed forever. It will now defined in terms of plank's constant. It will adopted on 20 May, 2019 (World Metrology Day - 20 May). The new definition of kg involves accurate weighing machine called "Kibble balance".

Supplementary Units

- Radian (rad) - for measurement of plane angle
- Steradian (sr) - for measurement of solid angle

Dimensional Formula

Relation which express physical quantities in terms of appropriate powers of fundamental quantities.

Use of dimensional analysis

- To check the dimensional correctness of a given physical relation
- To derive relationship between different physical quantities
- To convert units of a physical quantity from one system to another

$$n_1u_1 = n_2u_2 \Rightarrow n_2 = n_1\left(\frac{M_1}{M_2}\right)^a\left(\frac{L_1}{L_2}\right)^b\left(\frac{T_1}{T_2}\right)^c$$

where $u = M^aL^bT^c$

Limitations of dimensional analysis

- In Mechanics the formula for a physical quantity depending on more than three other physical quantities cannot be derived. It can only be checked.
- This method can be used only if the dependency is of multiplication type. The formulae containing exponential, trigonometrical and logarithmic functions can't be derived using this method. Formulae containing more than one term which are added or subtracted like $s = ut + \frac{1}{2}\ at^2$ also can't be derived.
- The relation derived from this method gives no information about the dimensionless constants.
- If dimensions are given, physical quantity may not be unique as many physical quantities have the same dimensions.
- It gives no information whether a physical quantity is a scalar or a vector.

SI PREFIXES

The magnitudes of physical quantities vary over a wide range. The CGPM recommended standard prefixes for magnitude too large or too small to be expressed more compactly for certain powers of 10.

PREFIXES USED FOR DIFFERENT POWERS OF 10

Power of 10	Prefix	Symbol	Power of 10	Prefix	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10^{1}	deca	da	10^{-18}	atto	a

UNITS OF IMPORTANT PHYSICAL QUANTITIES

Physical quantity	Unit	Physical quantity	Unit
Angular acceleration	rad s^{-2}	Frequency	hertz
Moment of inertia	kg – m^2	Resistance	kg m^2 A^{-2} s^{-3}
Self inductance	henry	Surface tension	newton/m
Magnetic flux	weber	Universal gas constant	joule K^{-1} mol^{-1}
Pole strength	A–m	Dipole moment	coulomb–meter
Viscosity*	poise	Stefan constant	watt m^{-2} K^{-4}
Reactance	ohm	Permittivity of free space (ε_0)	$coulomb^2/N–m^2$
Specific heat	J/kg°C	Permeability of free space (μ_0)	weber/A-m
Strength of magnetic field	newton A^{-1} m^{-1}	Planck's constant	joule–sec
Astronomical distance	Parsec	Entropy	J/K

*SI unit of viscosity is decapoise.

DIMENSIONS OF IMPORTANT PHYSICAL QUANTITIES			
Physical quantity	**Dimensions**	**Physical quantity**	**Dimensions**
Momentum	$M^1 L^1 T^{-1}$	Capacitance	$M^{-1} L^{-2} T^4 A^2$
Calorie	$M^1 L^2 T^{-2}$	Modulus of rigidity	$M^1 L^{-1} T^{-2}$
Latent heat capacity	$M^0 L^2 T^{-2}$	Magnetic permeability	$M^1 L^1 T^{-2} A^{-2}$
Self inductance	$M^1 L^2 T^{-2} A^{-2}$	Pressure	$M^1 L^{-1} T^{-2}$
Coefficient of thermal conductivity	$M^1 L^1 T^{-3} K^{-1}$	Planck's constant	$M^1 L^2 T^{-1}$
Power	$M^1 L^2 T^{-3}$	Solar constant	$M^1 L^0 T^{-3}$
Impulse	$M^1 L^1 T^{-1}$	Magnetic flux	$M^1 L^2 T^{-2} A^{-1}$
Hole mobility in a semi conductor	$M^{-1} L^0 T^2 A^1$	Current density	$M^0 L^{-2} T^0 A^1$
Bulk modulus of elasticity	$M^1 L^{-1} T^{-2}$	Young modulus	$M^1 L^{-1} T^{-2}$
Potential energy	$M^1 L^2 T^{-2}$	Magnetic field intensity	$M^0 L^{-1} T^0 A^1$
Gravitational constant	$M^{-1} L^3 T^{-2}$	Magnetic Induction	$M^1 T^{-2} A^{-1}$
Light year	$M^0 L^1 T^0$	Permittivity	$M^{-1} L^{-3} T^4 A^2$
Thermal resistance	$M^{-1} L^{-2} T^3 K$	Electric Field	$M^1 L^1 T^{-3} A^{-1}$
Coefficient of viscosity	$M^1 L^{-1} T^{-1}$	Resistance	$ML^2 T^{-3} A^{-2}$

SETS OF QUANTITIES HAVING SAME DIMENSIONS		
S.N.	**Quantities**	**Dimensions**
1.	Strain, refractive index, relative density, angle, solid angle, phase, distance gradient, relative permeability, relative permittivity, angle of contact, Reynolds number, coefficient of friction, mechanical equivalent of heat, electric susceptibility, etc.	$[M^0 L^0 T^0]$
2.	Mass or inertial mass	$[M^1 L^0 T^0]$
3.	Momentum and impulse.	$[M^1 L^1 T^{-1}]$
4.	Thrust, force, weight, tension, energy gradient.	$[M^1 L^1 T^{-2}]$
5.	Pressure, stress, Young's modulus, bulk modulus, shear modulus, modulus of rigidity, energy density.	$[M^1 L^{-1} T^{-2}]$
6.	Angular momentum and Planck's constant (h).	$[M^1 L^2 T^{-1}]$
7.	Acceleration, g and gravitational field intensity.	$[M^0 L^1 T^{-2}]$
8.	Surface tension, free surface energy (energy per unit area), force gradient, spring constant.	$[M^1 L^0 T^{-2}]$
9.	Latent heat capacity and gravitational potential.	$[M^0 L^2 T^{-2}]$
10.	Thermal capacity, Boltzmann constant, entropy.	$[ML^2 T^{-2} K^{-1}]$
11.	Work, torque, internal energy, potential energy, kinetic energy, moment of force, (q^2/C), (LI^2), (qV), (V^2C), (I^2Rt), $\frac{V^2}{R}t$, (VIt), (PV), (RT), (mL), $(mc\,\Delta T)$	$[M^1 L^2 T^{-2}]$
12.	Frequency, angular frequency, angular velocity, velocity gradient, radioactivity $\frac{R}{L}, \frac{1}{RC}, \frac{1}{\sqrt{LC}}$	$[M^0 L^0 T^{-1}]$
13.	$\left(\frac{\ell}{g}\right)^{1/2}, \left(\frac{m}{k}\right)^{1/2}, \left(\frac{L}{R}\right), (RC), (\sqrt{LC})$, time	$[M^0 L^0 T^1]$
14.	(VI), (I^2R), (V^2/R), Power	$[M L^2 T^{-3}]$

SOME FUNDAMENTAL CONSTANTS	
Gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}
Speed of light in vacuum (c)	3×10^8 ms^{-1}
Permeability of vacuum (μ_0)	$4\pi \times 10^{-7}$ H m^{-1}
Permittivity of vacuum (ε_0)	8.85×10^{-12} F m^{-1}
Planck constant (h)	6.63×10^{-34} Js
Atomic mass unit (amu)	1.66×10^{-27} kg
Energy equivalent of 1 amu	931.5 MeV
Electron rest mass (m_e)	9.1×10^{-31} kg $\equiv$ 0.511 MeV
Avogadro constant (N_A)	6.02×10^{23} mol^{-1}
Faraday constant (F)	9.648×10^4 C mol^{-1}
Stefan–Boltzmann constant (σ)	5.67×10^{-8} W m^{-2} K^{-4}
Wien constant (b)	2.89×10^{-3} mK
Rydberg constant (R_∞)	1.097×10^7 m^{-1}
Triple point for water	273.16 K (0.01°C)
Molar volume of ideal gas (NTP)	22.4 L = 22.4×10^{-3} m^3 mol^{-1}

KEY POINTS

- Trigonometric functions $\sin\theta$, $\cos\theta$, $\tan\theta$ etc and their arrangements θ are dimensionless.
- Dimensions of differential coefficients $\left[\frac{d^n y}{dx^n}\right] = \left[\frac{y}{x^n}\right]$
- Dimensions of integrals $\left[\int y dx\right] = [yx]$
- We can't add or subtract two physical quantities of different dimensions.
- Independent quantities may be taken as fundamental quantities in a new system of units.

PRACTICAL PHYSICS

Rules for Counting Significant Figures

For a number greater than 1

- All non-zero digits are significant.
- All zeros between two non-zero digits are significant. Location of decimal does not matter.
- If the number is without decimal part, then the terminal or trailing zeros are not significant.
- Trailing zeros in the decimal part are significant.

For a Number Less than 1

Any zero to the right of a non-zero digit is significant. All zeros between decimal point and first non-zero digit are not significant.

Significant Figures

All accurately known digits in measurement plus the first uncertain digit together form significant figure.

Ex. 0.108 → 3SF, 40.000 → 5SF,

1.23×10^{-19} → 3SF, 0.0018 → 2SF

Rounding off

6.87 → 6.9, 6.84 → 6.8, 6.85 → 6.8,

6.75 → 6.8, 6.65 → 6.6, 6.95 → 7.0

Order of magnitude

Power of 10 required to represent a quantity

$49 = 4.9 \times 10^1 \approx 10^1 \Rightarrow$ order of magnitude =1

$51 = 5.1 \times 10^1 \approx 10^2 \Rightarrow$ order of magnitude = 2

$0.051 = 5.1 \times 10^{-2} \approx 10^{-1}$ order of magnitude = -1

Propagation of combination of errors

Error in Summation and Difference :

$x = a + b$ then $\Delta x = \pm (\Delta a + \Delta b)$

Error in Product and Division

A physical quantity X depend upon Y & Z as $X = Y^a Z^b$ then maximum possible fractional error in X.

$$\frac{\Delta X}{X} = |a| \frac{\Delta Y}{Y} + |b| \frac{\Delta Z}{Z}$$

Error in Power of a Quantity

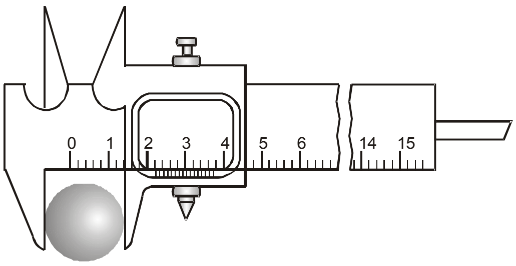
$$x = \frac{a^m}{b^n} \text{ then } \frac{\Delta x}{x} = \pm\left[m\left(\frac{\Delta a}{a}\right) + n\left(\frac{\Delta b}{b}\right)\right]$$

Least count

The smallest value of a physical quantity which can be measured accurately with an instrument is called the least count of the measuring instrument.

Vernier Callipers

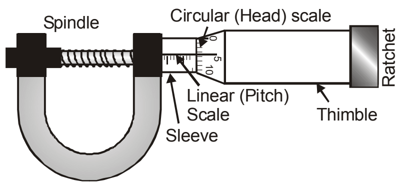
Least count = 1MSD – 1 VSD (MSD → main scale division, VSD → Vernier scale division)



Ex. A vernier scale has 10 parts, which are equal to 9 parts of main scale having each path equal to 1 mm then least count = 1 mm $-\frac{9}{10}$ mm = 0.1 mm [$\because$ 9 MSD = 10 VSD]

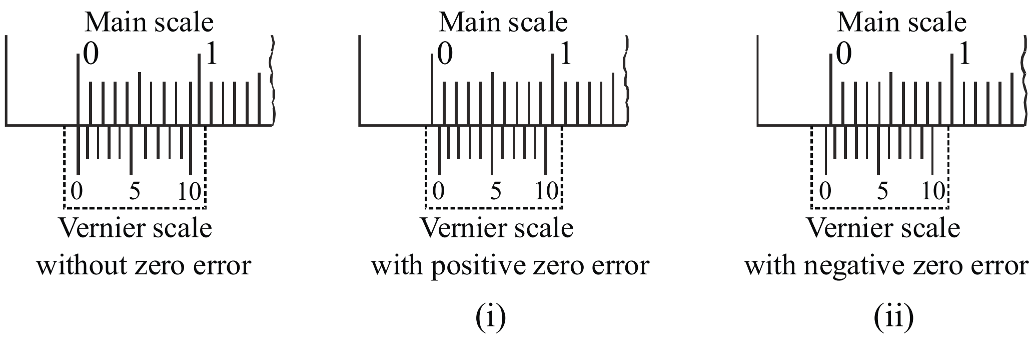
Screw Gauge

$$\text{Least count} = \frac{\text{pitch}}{\text{total no. of divisions on circular scale}}$$



Ex. The distance moved by spindle of a screw gauge for each turn of head is 1mm. The edge of the humble is provided with a angular scale carrying 100 equal divisions. The least count = $\frac{1\text{mm}}{100}$ = 0.01 mm

Zero Error in Vernier Callipers :



Calculation of zero error for vernier callipers :-

Positive zero error = (No. of Division of VS coincided with MS).LC

Negative zero error = (Total division in VS – No. of division of VS coincided with MS).LC

Correct reading with zero error

Correct reading = (Reading) – (Zero error)

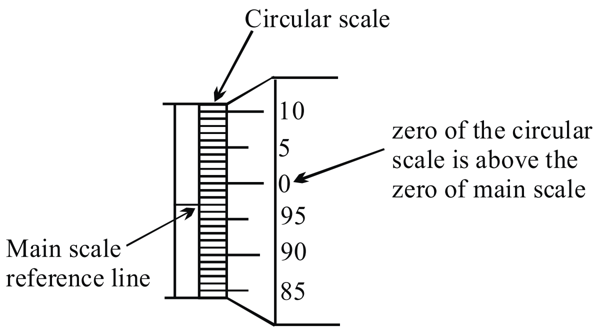
The zero error is always subtracted from the reading to get the corrected value.

Zero Error in Screw Gauge

If there is no object between the jaws (i.e. jaws are in contact), the screwgauge should give zero reading. But due to extra material on jaws, even if there is no object, it gives some excess reading. This excess reading is called Zero error.

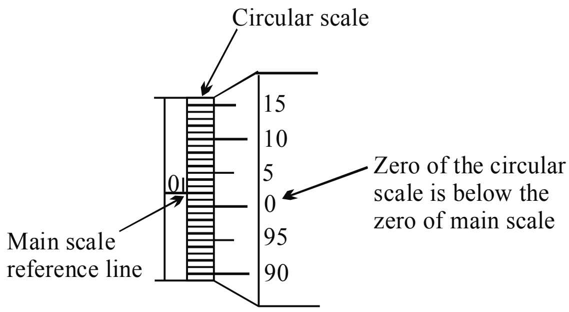
Negative Zero Error

(3 division error) i.e., –0.003 cm



Positive Zero Error

(2 division error) i.e., +0.002 cm



Calculation of zero error for screw gauge :-

Positive zero error = (No. of division of CS on MS).LC

Negative zero error = (Total division on CS – No. of division of CS on MS).LC

Correct reading = (Reading) – (zero error)

Remember :-

To get correct reading take zero error with their sign.

Positive zero error = + (Numerical value of zero error)

Negative zero error = – (Numerical value of zero error)