CHAPTER -01
UNITS, DIMENSIONS AND MEASUREMENTS

Units of Physical Quantities

Physical Quantity= Numerical Value × Unit

Fundamental Quantities in S.I. System and Their Units

S.No.	Physical Quantity	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

SYSTEMS OF UNITS

S.No.	MKS	CGS	FPS
1.	Length (m)	Length (cm)	Length (ft)
2.	Mass (kg)	Mass (g)	Mass (pound)
3.	Time (s)	Time (s)	Time (s)

Dimensional Formula

Describe relationships that represent physical quantities using specific powers of fundamental units.

Application of Dimensional Analysis

- To check the dimensional consistency of a given physical relationship.
- To derive relationship between various physical quantities.
- To convert units of a physical quantity from one system to another.

$n_1 u_1 = n_2 u_2 \Rightarrow n_2 = n_1 \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$ where $u = M^a L^b T^c$

Limitations of Dimensional Analysis:

1. Multiple physical quantities may have same dimensional Formula.
2. Numerical Constants canot be obtained.
3.This method can be used only if dependency is of multiplication type.
4. The physical quantity depending on more than three other physical quantities can't be derived.

Dimensional Formulae of Various Physical Quantities

Physical Quantity	Dimensional Formula
Area	$L \times L = L^2 = [M^0L^2T^0]$
Volume	$L \times L \times L = [M^0L^3T^0]$
Density	$\frac{M}{L^3} = [ML^{-3}T^0]$
Speed or Velocity	$\frac{L}{T} = [M^0LT^{-1}]$
Acceleration	$\frac{LT^{-1}}{T} = LT^{-2} = [M^0LT^{-2}]$
Momentum	$M \times LT^{-1} = [M^0LT^{-1}]$
Force	$M \times LT^{-2} = [MLT^{-2}]$
Work	$MLT^{-2} \times L = [ML^2T^{-2}]$
Energy	$[ML^2T^{-2}]$
Power	$\frac{ML^2T^{-2}}{T} = [ML^2T^{-3}]$
Pressure	$\frac{ML^1T^{-2}}{L^2} = [ML^{-1}T^{-2}]$
Moment of force or torque	$MLT^{-2} \times L = [ML^2T^{-2}]$
Gravitational constant 'G'	$\frac{[MLT^{-2}][L^2]}{M \times M} = [M^{-1}L^3T^{-2}]$
Impulse of a force	$MLT^{-2} \times T = [MLT^{-1}]$
Stress	$\frac{MLT^{-2}}{L^2} = [ML^{-1}T^{-2}]$
Strain	$[M^0L^0T^0]$
Coefficient of elasticity	$\frac{MLT^{-2}}{L^2} = [ML^{-1}T^{-2}]$

Surface tension	$\frac{MLT^{-2}}{L} = MT^{-2} = [ML^0T^{-2}]$
Coefficient of viscosity	$\frac{MLT^{-2}\times L}{L^2\times LT^{-1}} = [ML^{-1}T^{-1}]$
Angular velocity	$\frac{1}{T} = T^{-1} = [M^0L^0T^{-1}]$
Angular acceleration	$\frac{T^{-1}}{T} = T^{-2} = [M^0L^0T^{-2}]$
Moment of inertia	$ML^2 = [ML^2T^0]$
Angular momentum	$M \times LT^{-1} \times L = [ML^2T^{-1}]$
Planck's constant 'h'	$\frac{ML^2T^{-2}}{T^{-1}} = [ML^2T^{-1}]$
Force constant	$\frac{MLT^{-2}}{L} = MT^{-2} = [ML^0T^{-2}]$
Heat or enthalpy	$[ML^2T^{-2}]$
Specific heat	$\frac{[ML^2T^{-2}]}{[M][K]} = [M^0L^2T^{-2}K^{-1}]$
Latent heat	$\frac{[ML^2T^{-2}]}{[M]} = [M^0L^2T^{-2}]$
Thermal conductivity	$\frac{ML^2T^{-2}.L}{L^2.K.T} = [MLT^{-3}K^{-1}]$
Universal Gas Constant	$\frac{ML^{-1}T^{-2}L^3}{mol.K} = [ML^2T^{-2}K^{-1}\ mol^{-1}]$
Thermal conductivity	$\frac{[ML^2T^2.L]}{[L^2.K.T]} = [MLT^{-3}K^{-1}]$
Universal Gas Constant	$\frac{[ML^{-1}T^{-2}][L^3]}{[mol.K]} = [ML^2T^{-3}K^{-1}mol^{-1}]$
Boltzmann's Constant	$\frac{[ML^2T^{-2}]}{[K]} = [ML^2T^{-2}K^{-1}]$
Stefan's constant	$\frac{[ML^2T^{-2}]}{[L^2.T.K^4]} = [ML^0T^{-3}K^{-4}]$
Electric Charge	$[T.A] = [M^0L^0TA]$
Electrical potential	$\frac{[ML^2T^{-2}]}{[TA]} = [ML^2T^{-3}A^{-1}]$
Resistance	$\frac{[ML^2T^{-3}A^{-1}]}{[A]} = [ML^2T^{-3}A^{-2}]$
Capacitance	$\frac{[TA]}{[ML^2T^{-3}A^{-1}]} = [M^{-1}L^{-2}T^4A^2]$
Inductance	$\frac{[ML^2T^{-3}A^{-1}]}{[AT^{-1}]} = [ML^2T^{-2}A^{-2}]$

Permittivity of free space	$\frac{[AT.AT]}{[MLT^{-2}][L^2]} = [M^{-1}L^{-3}T^4A^2]$
Intensity of electric field	$\frac{[MLT^{-2}]}{[AT]} = [MLT^{-3}A^{-1}]$
Conductance	$\frac{1}{ML^2T^{-3}A^{-2}} = [M^{-1}L^{-2}T^{-3}A^2]$
Specific resistance or resistivity	$\frac{[ML^2T^{-3}A^{-2}][L^2]}{[L]} = [ML^3T^{-3}A^{-2}]$
Specific conductance of conductivity	$[M^{-1}L^{-3}T^3A^2]$
Electric dipole moment	$[AT][L] = [M^0LTA]$
Magnetic field	$\frac{MLT^{-2}}{AT.LT^{-1}} = [ML^0T^{-2}A^{-1}]$
Magnetic flux	$[MT^{-2}A^{-1}].[L^2] = [ML^2T^{-2}A^{-1}]$
Permeability of free space	$\frac{[L][MLT^{-2}]}{[A^2.L]} = [MLT^{-2}A^{-2}]$
Magnetic moment	$A.L^2 = [M^0L^2T^0A]$

Errors

- Distance of an object by parallax method, $D = \frac{\text{Basis}}{\text{Parallax angle}}$
- Absolute error = True value – Measured value = $[\Delta a_n]$
- True value = Arithmetic mean of the measured values $a_{mean} = \frac{a_1+a_2+\cdots+a_n}{n}$
- Relative error in the measurement of a quantity $= \frac{\Delta a_{mean}}{a_{mean}}$
- Percentage error $= \frac{\Delta a_{mean}}{a_{mean}} \times 100$
- Maximum permissible error in addition or subtraction of two quantities $(A \pm \Delta A) \pm (B \pm \Delta B)$ is $\Delta A + \Delta B$ (sum of absolute errors in both quantities)
- Maximum permissible relative error in multiplication or division of two quantities $(A \pm \Delta A)$ and $(B \pm AB)$: $\frac{\Delta A}{A} + \frac{\Delta B}{B}$ (sum of fractional errors in both quantities)
- When $z = \frac{a^p.b^q}{c^r}$, then maximum relative error in z is.

$$\frac{\Delta z}{z} = p\frac{\Delta a}{a} + q\frac{\Delta b}{b} + r\frac{\Delta C}{C}$$

SIGNIFICANT FIGURES

The following rules are observed in counting the number of significant figures in a given measured quantity:

All non-zero digits are significant

Example: 54.3 has three significant figures.
331.4 has four significant figures.

A zero becomes a significant figure if it appears between two non-zero digits.

Example: 6.03 has three significant figures.
4.604 has four significant figures.

Leading zeros or the zeros placed to the left of the number are never significant.

Example: 0.723 has three significant figures.
0.009 has one significant figure.

Trailing zeros or the zeros placed to the right of the number are significant.

Example: 8.240 has four significant figures.
723.00 has five significant figures.

In exponential notation, the numerical portion gives the number of significant figures.

Example: 1.41×10^{-2} has three significant figures.
1.41×10^{4} has three significant figures.

ROUNDING OFF

While rounding off measurements, we use the following rules by convention:

a) If the digit to be dropped is less than 5, then the preceding digit is left unchanged.

Example: x = 5.82 is rounded off to 5.8, again x = 4.84 is rounded off to 4.8.

b) If the digit to be dropped is more than 5, then the preceding digit is raised by 1.

Example: x = 3.47 is rounded off to 3.5, again x = 11.78 is rounded off to 11.8.

c) If the digit to be dropped is 5 followed by digits other than zero, then the preceding digit is raised by 1.
   Example: x = 14.351 is rounded off to 14.4, again x = 7.758 is rounded off to 7.8.

d) If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is left unchanged, if it is even.

Example: x = 9.250 becomes 9.2 on rounding off. again x = 17.650 becomes 17.6 on rounding off.

e) If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is raised by 1, if it is odd.

Example: x = 2.750 is rounded off to 2.8. again x = 19.150 is rounded off to 19.2.

Significant Figures in Calculation

1. The result of an addition or subtraction in the number having different precisions should be rounded off the same number of decimal places as are present in the number having the least number of decimal places. The rule is illustrated by the following examples:

(a)

33.3   Has only one decimal place
  3.11
+0.312

36.722
(Answer should be rounded off one decimal place)
Answer = 36.7.

(b)
62.831 Has three decimal place
− 24.5492
38.2818
(Answer should be rounded off 3 decimal places).
Answer = 38.282.

2. The answer to a multiplication or division is rounded off to the same number of significant figures as is possessed by the least precise term used in the calculation. The rule is illustrated by the following examples:

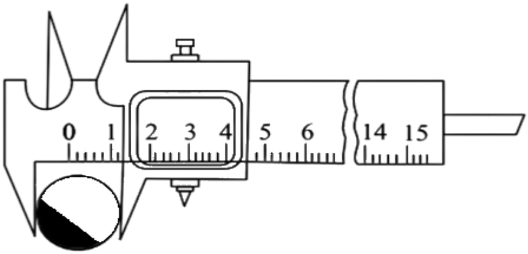
(a)
142.06 Has three decimal place
× 0.23
32.6738
0.23 has two significant figures
(Answer should have two significant figures)
Answer = 33

Order of Magnitude

Power of 10 required to represent a quantity
$49 = 4.9 \times 10^1 \approx 10^1$, order of magnitude =1
$51 = 5.1 \times 10^1 \approx 10^2$, order of magnitude = 2
$0.051 = 5.1 \times 10^{-2} \approx 10^{-1}$, order of magnitude = -1

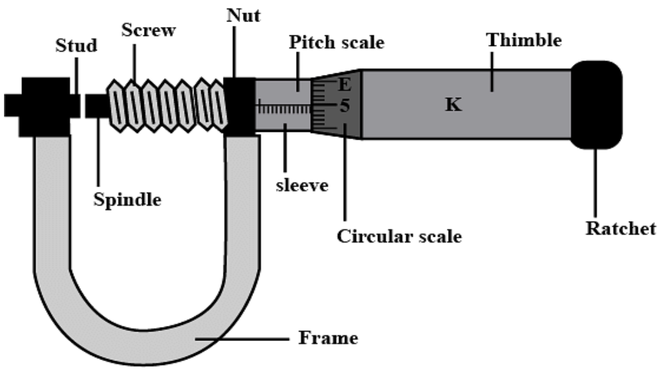
Vernier scale and screw gauge basics:

Vernier Callipers Least count = 1MSD – 1VSD
(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 part equal to 1 mm then least count = $1\,mm - \frac{9}{10}mm = 0.1$ [$\because 9\,MSD = 10\,VSD$].

Screw Gauge:



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