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measurement and instrumentation
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1.6 Systems of Units and standards

1.6.1. System of Units of Measurement

The unit is the standard measure of each kind of physical quantity without the unit, the measured value has no physical meaning. In order to perform the measurement, the physical quantities must be defined both in kind and magnitude. The number of times the unit occur in any given amount of the same quantity is the number of measure.

In science and engineering, to kinds of units are used:

1. The fundamental Units:

The fundamental unit, are measures of length, mass and time. These units are used in mechanics but since length, mass and time are fundamental to most other physical quantities besides those in mechanics, they are called the "primary fundamental units" Measures of certain physical quantities, in electrical, thermal, illumination and the amount of substance are also represented by fundamental units, but these unit, are used only when these particular classes are involved, and they therefore can be defined as "auxiliary fundamental units".

Thus, an agreed set of standard units (S'I units) or (system international d' units) has been defined and strong efforts were being made to encourage the adoption of this system throughout the world. The

SI measuring units and their symbols are given in table (1.1). two supplementary fundamental units for measuring angles are also included in this table

Table (1.1) fundamental S'I Units

	No.	Quantity	Unit	Symbol
Primary fundamental	1	Length	Meter	m
	2	Mass	Kilogram	kg
	3	Time	Second	S
Auxiliary fundamental	4	Electric Current	Amper	A
	5	Temperature	Kelvin	K
	6	Luminous intensity	Candela	Cd
	7	Matter	Mole	mol
Supplementary fundamental	8	Plane Angle	Radian	rad
	9	Solid angle	Steradian	sr

2. The derived Units

The derived units are those which can be expressed in terms of the fundamental units. Every derived unit is originated from some physical law defining that unit. The derived units may take special names such as the names of the famous scientists. Same of the derived units are listed in table (1.2)

Table (1.2) The derived units

No.	Quantity	Unit	Symbol
1-	Area	Square meter	m^2
2-	Volume	Cubic meter	m^3
3-	Velocity	Meter per second	m/s
4-	Acceleration	Meter per square second	m/s^2
5-	Angular velocity	Radian per second	rad/sec
6-	Angular acceleration	Radian per square second	rad/sec^2
7-	Density	Kilogram per cubic meter	Kg/m^3
8-	Mass flow rate	Kilogram per second	Kg/s

No.	Quantity	Unit	Symbol
9-	Volume flow rate	Cubic per second	m^3/s
10-	Force	Newton	N
11-	Pressure	Newton per square meter	n/m^2
12-	Torque	Newton-meter	n.m
13-	Moment of inertia	Kilogram-square meter	$Kg.m^2$
14-	Momentum	Kilogram-meter per second	Kg.m/s
15-	Work, energy	Joule	J
16-	Power	Watt	W
17-	Voltage	Volt	V
18-	Electric charge	Coulomb	C
19-	Electric field strength	Volt per meter	v/m
20-	Electric resistance	Ohm	Ω
21-	Electric capacitance	Farad	F
22-	Electric inductance	Henry	H
23-	Electric conductance	Siemens	S
24-	Resistivity	Ohm-meter	Ω.m
25-	Permittivity	Farad per meter	F/m
26-	Permeability	Henry per meter	H/m
27-	Current density	Amper per square meter	A/m^2
28-	Magnetic flux	Weber	Wb
29-	Magnetic flux density	Tesla	T
30-	Magnetic field strength	Amper per meter	A/m
31-	Frequency	Hertz	Hz
32-	Luminous flux	Lumen	Lm
33-	Luminance	Candela per square meter	Cd/m^2
34-	Illumination	Lux	lx (lm/m^2)
35-	Molarity	Mole per kilogram	mol/kg
36-	Molar volume	Cubic meter per mole	M^3/mol
37-	Molar energy	Joule per mole	J/mol
38-	Kinematic viscosity	Newton- second per sq.meter	$n.s/m^2$
39-	Dynamic viscosity	Newton-second per sq.meter	$n.s/m^2$

No.	Quantity	Unit	Symbol
40-	Thermal conductivity	Watt per meter-kelvin	w/m.k

Some of units are inconveniently large or small in practical circumstances. Hence, standard multiples and sub-multiples of the base "ten" are commonly used. Table (1.3) shows these multiples and sub-multiples with their symbols and prefix.

Table (1.3) Multiples and sub-multiples of SI units

No.	Prefix	Power of 10	Symbol
1-	Exa	10^{18}	E
2-	Peta	10^{15}	P
3-	Tera	10^{12}	T
4-	Giga	10^{9}	G
5-	Mega	10^{6}	M
6-	Kilo	10^{3}	K
7-	Hecto	10^{2}	H
8-	Deca	10	Da
9-	Deci	10^{-1}	D
10-	Centi	10^{-2}	C
11-	Milli	10^{-3}	M
12-	Micro	10^{-6}	
13-	Nano	10^{-9-}	N
14-	Pico	10^{-12}	P
15-	Femto	10^{-15}	F
16-	Atto	10^{-18}	a

The English system of units uses the foot (ft), the pound-mass (lb) and the second (s) as the three fundamental units of length, mass and time respectively.

Although the measure of length weight are legacies of the Roman occupation of Britcin and therefore rather poorly defined, the inch (defined as one-twelfth of the foot) has since been fixed at exactly 25.4

mm similarly, the measure for the pound (lb) has been determined as exactly 0.45359237 kg. These two figures allow all units in the English system to be converted into SI units. Table (1.4) lists some of common conversion factors for English into SI units.

Table (1.4) English units into SI conversions

No.	Quantity	English unit	Symbol	SI unit
1	Length	Foot Yard Inch Mile Nautical mile	Ft Yd In Mi N mi	0.3048 m 0.9144 m 25.4 mm 1.609 km 1.852 km
2	Mass	Pound Ounce Slug	Lb Oz Slug	0.4539237 kg 28.35 g 14.6 kg
3	Force	poundal	Pdl	0.138255 N
4	Power	Horse power	Hp	745.7 w
5	Work, energy	Foot-poundal	Ft-pdl	0.0421401 J
6	Temperature	Fahrenheit	F	C = – (F – 32) C° K = $\frac{5}{q}(F+459.67)k^{\circ}$

Example (1.1)

The floor area of an office building is 5000 m^2 calculate the floor area in ft^2

Solution

1 ft = 0.3048 m

m=1/0.3048 = 3.28 ft =10.7639 ft^2

A = 5000 m^2 * 10.7639 = 53819.552 ft^2

Example (1.2)

The velocity of light n free space is expressed as 3 X 10^6 m/s. Give the velocity of light in (i) km/hr (ii) ft/s

Solution

(i) (3 X 10^6 /1000) ÷ (1/3600) = 108*10^5 km/hr

(ii) 3 X 10^6 *3.2808 =9842400 ft/s

H.W (1.1)

If the density of water is given as 62.5 lb/ft^3, calculate the density of water in:

(i) lb/in^3 (Ans. D = 0.0362 lb/in^3)

(ii) g/cm^3 (Ans. 1 g/cm^3)

1.6.2 measurement standards

A Standard of measurement is a physical representation of the unit of measurement. The unit may be realized by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants.

There are in general four levels of standards of measurements:

1. International standards

The international standards are defined by international agreement. They represent certain units of measurements to the closest possible accuracy that production and measurement technology allow. International standards are periodically evaluated and checked by absolute measurement in terms of the fundamental units. These standards are maintained at the international bureau of weight, and measures at sevres, near Paris and are available for calibration of primary standards only.

2. Primary standards

The primary standards are preserved by national standard laboratories in different parts of the world. For **Example**, the national Burea of standards (NBS) in Washington, and the national physical Laboratory (NPL) in great Britain. The primary standards are calibrated against international standards and their main function is to calibrate the secondary standards.

3. Secondary standards

The secondary standards are maintained as reference standards in industrial measurement laboratories. These standards are periodically sent to national standard laboratories for calibration with the primary standards.

4. Working standards

These are the principal tools of any measurement laboratory. Working standards are used to check and calibrate the laboratory instruments and the manufacture parts and components. The working standards are preserved in the quality control department of the measurement laboratory.

The standards units for the measurement of the physical quantities have been defined and progressively improved over the years. The latest standards for defining the units used for measuring a range of physical quantities or variables are given in table (1.5).

Table (1.5) Definition of standard units.

No.	Physical quantity	Standard unit	Definition
1-	Length	Meter	The length of path travelled by light in an interval of 1/299792458 seconds.
2-	Mass	Kilogram	The mass of a platinum-iridum cylinder kept in the international Bureau of Weight and measures at sevres, Paris, France
3-	Time	Second	9.9192631770 X 10^9 cycles of radiation from vaporized caesium-133.
4-	Current	Amper	Is the current flowing throw two infinite lt long parallel conductors of negligible cross-section placed one meter apart in a vacuum and producing a force of 2 X 10^7 newton's per meter length of the conductor
5-	Temperature	Kalvin	The temperature difference between absolute zero and the triple point of water is defined as 273.16 kelvin
6-	Luminous intensity	Candela	Is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz and with a radiant density in that direction of 1.464 mw/sr
7-	Matter	Mole	The number of atoms in a 12 g mass of

No.	Physical quantity	Standard unit	Definition
			carbon-12

Exercise (1)

1- Define the following terms:

(i) measurement (ii) Instrumentation (iii) instrument (iv) transducer

2- Explain the configuration of the measuring system by a block diagram.

3- List the measurement methods, and explain the points according to which the suitable methods and explain the points according to which the suitable method can be selected.

4- List the types of the measuring instruments.

5- Explain the advantages of electronic and digital instrument over the electrical and mechanical instrument.

6- Discuss briefly the functions of the measuring instruments.

7- Tabulate the SI unit, and give their symbols and the quantities that they are used to measure.

8- Give the SI units of the following quantities

(i) Time (ii) matter (iii) acceleration (iv) density (v) torque