# *Lecture 1,2*

# Units, Dimensions and Standards

## Objectives

After completing this chapter, you should be able to:

- Understand the meaning of unit.
- Know the difference between the fundamental and derived unit.
- Know the SI units for various physical quantities.
- List the advantages and disadvantages of S.I units.

## 1.1 Introduction

There are several types of quantities in the field of engineering which need to be measured or expressed in day-to-day work. This includes physical, chemical, mechanical quantities etc. In order to record or to compare magnitude of quantities some magnitude of each kind must be taken as basis or unit. To measure or to define any quantity we need a well-defined unit. There are fundamental and supplementary fundamental units. These units are used to define all quantities. Many systems like SI (International System of Units), CGS (Centimetre-gram-second System), MKS (Metre-kilogram-second) etc. are developed to define the physical quantity.

## 1.2 Unit

The standard measurement of any physical quantity is known as Unit. The number of times the unit occurs in any given amount of the same quantity is the number of measure. For example 100 metres, we know that the metre is the unit of length and that the number of units of length is one hundred. The physical quantity, length, is therefore defined by the unit metre.

## 1.3 Fundamental and Derived Units

The units which are independent and are not related to each other are known as ***Fundamental Unit***. These units do not vary with time, temperature and pressure etc. There are seven fundamental units, as given below:

***Fundamental Units***: *length, mass, time, electric current, temperature, luminous intensity and quantity of matter.*

The units which are derived from fundamental units or which can be expressed in terms of the fundamental units are called ***Derived Unit***. Every derived unit originates from some physical law defining that unit. This unit is recognized by its dimensions, which can be defined as the complete algebraic formula for the derived unit. Like area, volume, velocity etc. For example, the area of rectangle is proportional to its length ($l$) and breadth ($b$) or $A = l \times b$. If the metre has been chosen as the unit of length, then the unit of area is $m^2$. The derived unit for area ($A$) is then the square metre ($m^2$).

For convenience, some derived units have been given new names. For example, the derived unit of force in the S.I. system is called the Newton (N), instead of the dimensionally correct name kg- $m/s^2$.

## 1.4 International System of Units

The International System of Units (abbreviated S.I. from the French *Système international d'unités*) is the modern form of the metric system and is generally a system of units of measurement devised around seven base units and the convenience of the number ten. It is the world's most widely used system of measurement, both in everyday commerce and in science.

**Table 1.1** Definitions of Standard Units

| *Physical Quantity* | *Standard Unit* | *Definition* |
|---|---|---|
| Length | metre | The length of path travelled by light in an interval of 1/299 792 458 seconds |
| Mass | kilogram | The mass of a platinum–iridium cylinder kept in the International Bureau of Weights and Measures, S`evres, Paris |
| Time | second | $9.192631770 \times 10^9$ cycles of radiation from vaporized caesium-133 (an accuracy of 1 in $10^{12}$ or 1 second in 36000 years) |
| Temperature | kelvin | The temperature difference between absolute zero and the triple point of water is defined as 273.16 kelvin |
| Current | ampere | One ampere is the current flowing through two infinitely long parallel conductors of negligible cross-section placed 1 metre apart in a vacuum and producing a force of $2 \times 10^{-7}$ Newtons per metre length of conductor |
| Luminous intensity | candela | One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz ($\times 10^{12}$ Hz) and with a radiant density in that direction of 1.4641 mW/steradian. (1 steradian is the solid angle which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius) |
| Matter | mole | The number of atoms in a 0.012 kg mass of carbon-12 |

The system has been nearly globally adopted. Three countries which have not adapted are Burma (Myanmar), Liberia, and the United States.

The International System (or S.I. system) of Units consists of a set of units together with a set of prefixes. The units of S.I. can be divided into two subsets. There are seven base units: Every base unit represents different kinds of physical quantities. From these seven base units, several other units are derived. In addition to the S.I. units, th [illegible] units accepted for use with SI which includes some commonly used units such as the litre. Table 1.1 shows the standard units and definition.

The S.I. system is divided into three classes: Fundamental Unit shown in Table 1.2, Supplementary Unit shown in Table 1.3 and Derived Unit shown in Table 1.4.

**Table 1.2** S.I. Fundamental Units

| *Quantity* | *Standard Unit* | *Symbol* |
|---|---|---|
| Length | metre | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | ampere | A |
| Temperature | Kelvin | K |
| Luminous intensity | candela | cd |
| Matter | mole | mol |

There are two supplementary units which are added to the S.I. system of units.

Radian for the plane angles: The plane angles subtended by an arc of a circle equal in length to the radius of the circle. It is denoted as rad.

The solid angle subtended at the centre of a sphere by the surface whose area is equal to the square of the radius of the sphere. It is denoted as sr.

Supplementary units are neither base units nor derived from base units. It is given in Table 1.3 below:

**Table 1.3** Supplementary Fundamental Units

| *Quantity* | *Standard unit* | *Symbol* |
|---|---|---|
| Plane angle | radian | rad |
| Solid angle | steradian | sr |

The number of quantities in science is without limit, and it is not possible to provide a complete list of derived units. However, Table 1.4 shows some examples of derived unit:

**Table 1.4** S.I. Derived Units

| *Quantity* | *Standard Unit* | *Unit Standard* |
|---|---|---|
| Area square | metre | $m^2$ |
| Volume cubic | metre | $m^3$ |
| Velocity | metre per second | m/s |
| Acceleration | metre per second squared | $m/s^2$ |
| Angular velocity | radian per second | rad/s |
| Angular acceleration | radian per second squared | $rad/s^2$ |
| Density | kilogram per cubic metre | $kg/m^3$ |

| | | |
|---|---|---|
| Specific volume | cubic metre per kilogram | $m^3/kg$ |
| Mass flow rate | kilogram per second | kg/s |
| Volume flow rate | cubic metre per second | $m^3/s$ |
| Force | Newton | N |
| Pressure | Newton per square metre | $N/m^2$ |
| Torque | Newton metre | Nm |
| Momentum | kilogram metre per second | kgm/s |
| Moment of inertia | kilogram metre squared | $kgm^2$ |
| Kinematic viscosity | square metre per second | $m^2/s$ |
| Dynamic viscosity | Newton second per square metre | $Ns/m^2$ |
| Work, energy, heat | joule | J |
| Specific energy | joule per cubic metre | $J/m^3$ |
| Power | watt | W |
| Thermal conductivity | watt per metre Kelvin | W/mK |
| Electric charge | coulomb | C |
| Voltage, e.m.f., pot. diff. | volt | V |
| Electric field strength | volt per metre | V/m |
| Electric resistance | ohm | Ω |
| Electric capacitance | farad | F |
| Electric inductance | Henry | H |
| Electric conductance | siemen | S |
| Resistivity | ohm metre | Ωm |
| Permittivity | farad per metre | F/m |
| Permeability | Henry per metre | H/m |
| Current density | ampere per square metre | $A/m^2$ |
| Magnetic flux | Weber | Wb |
| Magnetic flux density | tesla | T |
| Magnetic field strength | ampere per metre | A/m |
| Frequency | hertz | Hz |
| Luminous flux | lumen | lm |
| Luminance | candela per square metre | $cd/m^2$ |
| Illumination | lux | lx |
| Molar volume | cubic metre per mole | $m^3/mol$ |
| Molarity | mole per kilogram | mol/kg |
| Molar energy | joule per mole | J/mol |

## 1.5 Advantages of S.I. Units

Although there are several advantages of S.I. units yet the following are important from the subject point of view:

1. S.I. unit measurement is a coherent system of units, *i.e.*, a system based on a certain set of fundamental units, from which all derived units are obtained by multiplication or division without introducing numerical factors.

2. S.I. unit measurement is a rational system of units, as it assigns only one unit to a particular quantity. For example, joule is the unit assign to all types of energies. This is not so in other system of units. For example, in MKS system of units, mechanical energy is in joules, heat energy is in calories and electrical energy is in Kilowatt hour.
3. S.I. unit measurement system is an absolute system of units. There are no gravitational systems of units in this system. Thus the use of factor '*g*' is eliminated.
4. S.I. unit measurement system is a metric system, *i.e.*, the multiples and the submultiples of units are expressed as the exponents of 10.
5. In the current electricity, the absolute unit of electrical quantities like ampere (A) for electric current, volt (V) for potential difference, ohm (Ω) for resistance, Henry (H) for inductance, farad (f) for capacitance and so on, happens to be the practical units of these quantities.

The S.I. system of units applies to all branches of science, but the MKS system of units is confined to mechanics only.

## 1.6 Disadvantages of S.I. Units

Following are some of the disadvantages of S.I units:

1. The non S.I. "time units" minute and hour will still continue to be used until the clocks and watches are all changed to kilo seconds and mega second etc.
2. The base unit kilogram (kg) includes a prefix, which creates an ambiguity in the use of multipliers with gram.

## 1.7 Prefixes and Suffixes

It is often convenient to use units which are a multiple or fraction of the basic unit. The metric system, formally known as the International System of Units, defines a number of prefixes to denote powers of ten. The current official set is tabulated here: Prefixes used by the International System of Units (S.I.)

Prefixes used by the International System of Units (S.I.) are shown in Table 1.5.

**Table 1.5**

| *Prefix* | *Factor* | *Symbol* |
|---|---|---|
| Exa | $10^{18}$ | E |
| Peta | $10^{15}$ | P |
| Tera | $10^{12}$ | T |
| Giga | $10^{9}$ | G |
| Mega | $10^{6}$ | M |
| kilo | $10^{3}$ | k |
| Hector | $10^{2}$ | h |
| Deca | 10 | da |
| Deci | $10^{-1}$ | d |
| Centi | $10^{-2}$ | c |
| Milli | $10^{-3}$ | m |
| Micro | $10^{-6}$ | μ |
| Nano | $10^{-9}$ | n |
| Pico | $10^{-12}$ | p |
| Femto | $10^{-15}$ | f |
| Atto | $10^{-18}$ | a |

## 1.8 S.I. Electrical Units

Table 1.6 below shows the S.I Units for electrical quantities.

**Table 1.6**

| *Physical Quantity* | *Quantity symbol* | *SI Unit* | *Unit Symbol* | *Expression in SI base units* | *Alternative expressions* |
|---|---|---|---|---|---|
| frequency | $\nu, f$ | hertz | Hz | $s^{-1}$ | - |
| force | $F$ | newton | N | kg m $s^{-2}$ | J $m^{-1}$ |
| pressure | $p$ | pascal | Pa | kg $m^{-1}$ $s^{-2}$ | N $m^{-2}$ |
| energy (all forms) | $E, U, V, W$ etc. | joule | J | kg $m^{2}$ $s^{-2}$ | Nm = C V = V A s |
| power | $P$ | watt | W | kg $m^{2}$ $s^{-3}$ | J $s^{-1}$ = VA |
| electric charge | $Q$ | coulomb | C | A s | - |
| electric potential difference | $E, \varphi, \zeta, \Phi, \eta$ etc. | volt | V | kg $m^{2}$ $s^{-3}$ $A^{-1}$ | J $A^{-1}$ $s^{-1}$ = J $C^{-1}$ |
| electrical capacitance | $C$ | farad | F | $A^{2}$ $s^{4}$ $kg^{-1}$ $m^{-2}$ | C $V^{-1}$ |
| electrical resistance | $R$ | ohm | Ω | kg $m^{2}$ $s^{-3}$ $A^{-2}$ | V $A^{-1}$ |
| electrical conductance | $G$ | siemens | S | $A^{2}$ $s^{3}$ $kg^{-1}$ $m^{-2}$ | A $V^{-1}$ = $\Omega^{-1}$ |
| magnetic flux | $\Phi$ | weber | Wb | kg $m^{2}$ $s^{-2}$ $A^{-1}$ | V s = T $m^{2}$ |
| magnetic induction | $B$ | tesla | T | kg $s^{-2}$ $A^{-1}$ | Wb $m^{-2}$ = N $A^{-1}$ $m^{-1}$ |
| inductance | $L, M$ | henry | H | kg $m^{2}$ $s^{-2}$ $A^{-2}$ | V $A^{-1}$ s = Wb $A^{-1}$ |
| luminous flux | $\Phi$ | lumen | lm | cd sr | - |
| illumination | $E$ | lux | lx | cd sr $m^{-2}$ | lm $m^{-2}$ |
| Celsius temperature | $t$ | degree Celsius | °C | K | - |
| plane angle | $\alpha, \beta, \gamma, \theta, \Phi$ | radian | rad | $mm^{-1}$ | dimensionless |
| solid angle | $\omega, \Omega$ | steradian | sr | $m^{2}$ $m^{-2}$ | dimensionless |

## 1.9 S.I. Unit for Temperature

The S.I. unit for temperature is the Kelvin (K). Temperature can be expressed using three different scales: Fahrenheit, Celsius, and Kelvin. Although 0 K is much colder than 0°C, a change of 1° K is equal to a change of 1°C. Three temperature scales are shown in Fig. 1.1.

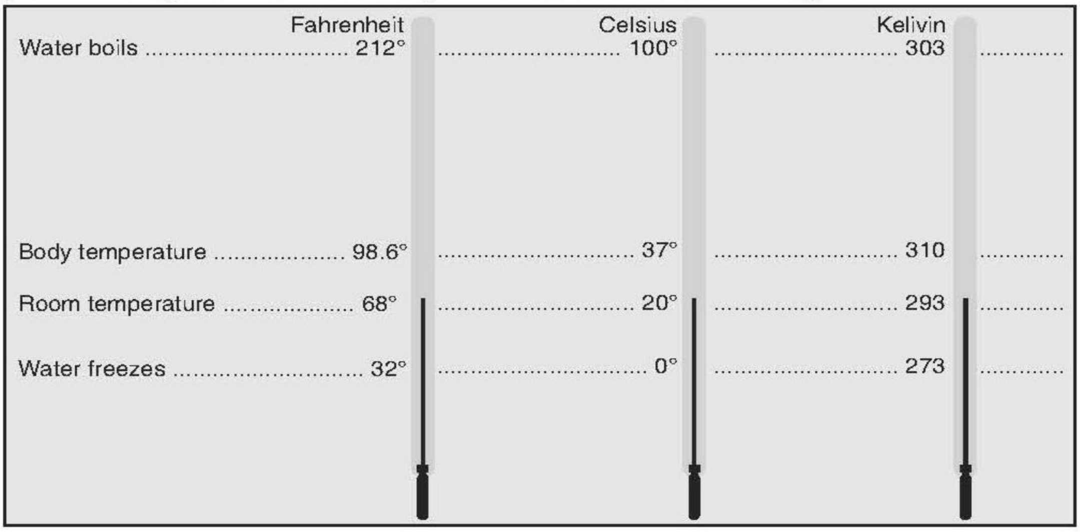


**Fig. 1.1.**

Table 1.7 shows the conversion of temperature from degree Celsius to Farenheit or Kelvin and vice versa. Go through the examples for more clarity.

**Table 1.7**

| *To convert* | *Use this equation* | *Example* |
|---|---|---|
| Celsius to Fahrenheit<br>°C → °F | $°F = \left(\frac{9}{5} \times °C\right) + 32$ | Convert 45°C to °F.<br>$°F = \left(\frac{9}{5} \times 45°C\right)$ |
| Fahrenheit to Celsius<br>°F → °C | $°C = \frac{5}{9} \times (°F - 32)$ | Convert 68°F to °C<br>$°C = \frac{5}{9} \times (68°F - 32) = 20°C$ |
| Celsius to Kelvin<br>°C → K | K = °C + 273 | Convert 45°C to K.<br>K = 45°C + 273 = 318 K |
| Kelvin to Celsius<br>K → °C | °C = K – 273 | Convert 32 K to °C.<br>°C = 32 K – 273 = –241 °C |

## 1.10 Other Unit Systems

There are various unit systems that have been derived in the past and were used in different parts of the world. These systems are given below:

### *Systems of Mechanical Units*

There are four general systems of mechanical units used in engineering. All these systems are given below:

**(*a*) FPS System.** In FPS system the units of fundamental quantities, length, mass and time are foot, pound and second respectively.

**(*b*) English System.** 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. For example the unit of density will be expressed in $lb/ft^3$ and unit of acceleration in $ft/s^2$.

**(*c*) CGS System.** In CGS system the units of fundamental quantities, length, mass and time are centimetre, gram and second respectively.

**(*d*) MKS System.** In MKS system the units of fundamental quantities, length, mass and time are metre, kilogram and second respectively.

### *Systems of Electrical Units*

The three basic concepts and three fundamental units are sufficient for description and measurement in mechanical science, experience shows that, in electrical science, four concepts or dimensions and four arbitrarily defined fundamental units are necessary to obtain a complete system of dimensions and units. At least one of these four units must be electrical in character. The various electrical unit systems used are:

**(*a*) The CGS Electrostatic System of Units (CGS ESU).** It is an absolute system based on the centimetre, gram and second as the fundamental mechanical units and permittivity (ε) of medium as fourth fundamental unit. The unit of permittivity is of such a size that the measured number of permittivity for free space is unity.

**(*b*) The CGS Electromagnetic System of Units (CGS EMU).** It is another absolute system based on the centimetre, gram and second as the fundamental mechanical units and permeability (μ) of medium as fourth fundamental unit. The unit of permeability is of such a size that the measured number of permeability for free space is unity.

(*c*) **The MKS System of Units.** It is an absolute system based on the metre, kilogram and second as the fundamental mechanical units and permeability (μ) of medium as fourth fundamental unit. The unit of permeability is of such a size that the measured number of permeability for free space is $10^{-7}$.

## 1.11 Dimensions

The unique quality of every quantity which distinguishes it from all other quantities is called dimension.In mechanics the three fundamental units are length, mass and time. Their dimensional symbols are:

Length = [L], Mass = [M], Time = [T]

There are some more units which are, charge, temperature and current.

Charge = [Q], Temperature = [K], Current = [I]

The square brackets indicate the dimensional notation only.The system of unit employs, mass,length, time and charge as four fundamental concepts. The system of unit employing mass, length, time and current as four fundamental concepts is termed as S.I. system. The dimension of various electrical and magnetic quantities can be derived from the known relationship between them. Some are given below:

1. Current = [I]
2. Charge

   Charge is the quantity of electricity = Current × Time

$$[Q] = [IT]$$

3. Potential Difference

$$\text{Potential Difference} = (\text{Work done})/(\text{Quantity of electricity})$$

$$[V] = \frac{[E]}{[Q]} = \frac{[M\,L^2\,T^{-2}]}{[IT]} = [M\,L^2\,T^{-3}\,I^{-1}]$$

4. Resistance

$$\text{Resistance} = \frac{\text{Potential Difference}}{\text{Current}}$$

$$[R] = \frac{[V]}{[I]} = \frac{[M\,L^2\,T^{-3}\,I^{-1}]}{[I]} = [M\,L^2\,T^{-3}\,I^{-2}]$$

The various powers of the fundamental units represent the dimensions of any derived unit. For example the dimension symbols for the derived unit of speed is $LT^{-1}$ and that for acceleration is $LT^{-2}$. All other mechanical quantities are expressed in terms of three fundamental quantities *i.e.* length, mass and time.

## 1.12 Standards

A standard of measurement is a physical representation of a unit of measurement. A unit is realized by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants. For example, the fundamental unit of mass in the international system (SI) is the kilogram, defined as the mass of a cubic decimetre of water as its temperature of maximum density of 400°C.

## 1.13 Classification of Standards

The standards are classified according to their function and application in following type:

1. International Standards
2. Primary Standards

3. Secondary Standards
4. Working Standards

## 1.14 International Standards

The international standards are defined by international agreement. They represent certain units of measurement to the closest possible accuracy that production and measurement technology allow. These standards are periodically checked by absolute measurements in terms of the fundamental units. These standards are maintained at international bureau of weights and measure and are not available to the ordinary users for measurements.

International ohm: It is defined as the resistance offered by a column of mercury having a mass of 14.4521 grams, uniform cross-section areas length of 106.300 cm, to the flow of constant current at the melting point of ice.

International ampere: It is an unvarying current, which when passed through a solution of silver nitrate in water deposits silver at the rate 0.00111800 grams/sec (g/s).

## 1.15 Primary Standards

The primary (basic) standards are maintained by national standards laboratories in different parts of the world. A primary standard is a standard that is accurate enough that it is not calibrated by or subordinate to other standards. The main function of the primary standards is the calibration and verification of secondary standards. These standards are not available for use outside the national laboratories.

## 1.16 Secondary Standards

Secondary standards are the basic reference standards used in industrial measurement laboratories. These standards are maintained by the particular involved industry and are checked locally against other reference standards in area. Secondary standards are generally sent to the international standards laboratories on a periodic basis for calibration and comparison against the primary standards. They are then returned to the industrial user with certification of their measured value in terms of the primary standard.

## 1.17 Working Standards

Working standards are the principle tools of a measurement laboratory. They are used to check laboratory instruments for accuracy and performance. These standards are used to perform comparison measurements in industrial application. For example, manufacturers of components such as capacitors, resistors etc. use a standard called a working standard for checking the

## MULTIPLE CHOICE QUESTIONS

**1.** The unit of quantity of electricity is

(*a*) volt (*b*) coulomb (*c*) ohm (*d*) joule

**2.** Electromotive force is provided by

(*a*) resistance (*b*) a conducting path
(*c*) an electric current (*d*) an electrical supply source

**3.** The coulomb is a unit of

(*a*) power (*b*) voltage
(*c*) energy (*d*) quantity of electricity

**4.** In order that work may be done

(*a*) a supply of energy is required
(*b*) the circuit must have a switch
(*c*) coal must be burnt
(*d*) two wires are necessary

**5.** The ohm is a unit of

(*a*) charge
(*b*) resistance
(*c*) power
(*d*) current

**6.** The unit of current is the

(*a*) volt
(*b*) coulomb
(*c*) joule
(*d*) ampere

**7.** Value of Femto is

(*a*) $10^{-9}$
(*b*) $10^{-12}$
(*c*) $10^{-15}$
(*d*) $10^{-18}$

## ANSWERS

**1.** (*b*) **2.** (*c*) **3.** (*d*) **4.** (*a*) **5.** (*b*) **6.** (*d*)
**7.** (*c*)