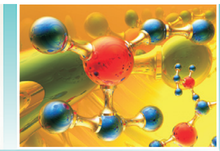


SI Units

COMMON SYSTEMS OF MEASUREMENTS

There are two common systems of measurement.

(1) Metric System

This is a decimal system of weights and measures originally based on the meter as the unit of length and the kilogram as the unit of mass.

(2) SI System

The International system of units was adopted by the 11th General Conference of Weights and Measures in 1960. The **SI units are widely used but they have not been fully accepted by the scientific community.**

In fact, metric system is still used in most countries. The American textbooks make use of the metric system freely. May be that America reverts to the metric system over the years.

In this book we have used the metric units throughout. However, at several places the SI units have also been used as we feel that in the present state of confusion the student should be conversant with both types of units. Here, we will discuss the metric and the SI units as also the conversion factors.

TABLE 1. SI BASE UNITS

Physical Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Number of particles	mole	mol

SI UNITS OF LENGTH

The SI unit of length is the meter (m). Fractions and multiples of SI units are named by adding appropriate prefixes. The commonly used metric length units are listed in Table 2.

TABLE 2. COMMON METRIC LENGTH UNITS

Unit	Symbol	Relation
meter	m	
kilometer	km	1 km = 10^{3} m
decimeter	dm	1 dm = 10^{-1} m
centimeter	cm	1 cm = 10^{-2} m
millimeter	mm	1 mm = 10^{-3} m
micrometer	mm	1 µm = 10^{-6} m
nanometer	nm	1 nm = 10^{-9} m
picometer	pm	1 pm = 10^{-12} m
angstrom	Å	1Å = 10^{-8} cm = 10^{-10} m

Even though the unit **angstrom** (Å) is not part of the SI system, it is still used for distances between atoms. Currently, the interatomic distances are sometimes reported in units of nanometers (nm) or picometer (pm).

$$1\,\text{nm} = 10\,\text{Å}$$
$$1\,\text{pm} = 10^{-2}\,\text{Å}$$
$$1\,\text{nm} = 10^{-3}\,\text{pm}$$

It may be noted that **the metric symbols are not changed into plurals.** Thus five centimeters of length is written as

Correct	Incorrect
5 cm	5 cm. 5 c.m. 5 cms

SI UNITS OF VOLUME

The derived SI unit of volume is

Cubic meter m^3

This is the volume of a cube that is 1 meter on each edge. The related units of volume which are also used are :

Cubic centimeter cm^3

Cubic decimeter dm^3

Another common measure of volume is the litre (a non-SI unit) which is denoted by **L** (ℓ or l).

A liter is the volume occupied by a cube 10 cm on edge. That is,

$$1\,\text{L} = (10\,\text{cm})^3 = 1000\,\text{cm}^3$$

Also $1\,\text{L} = 1000\,\text{mL}$

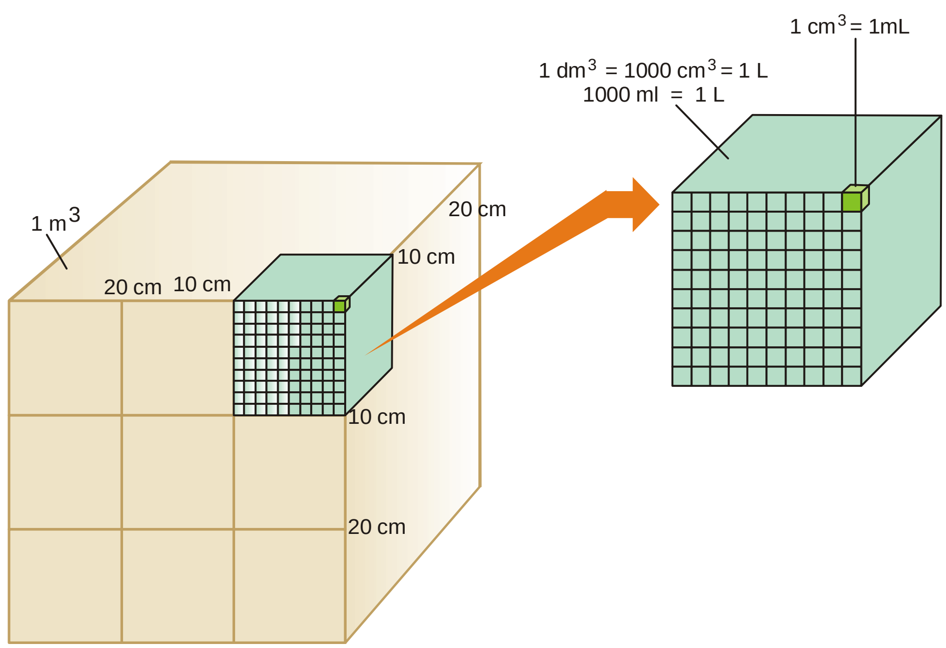


Figure 1
Relationship between length and volume.

Therefore $1000\,mL = 1000\ cm^3$

$1\ mL = 1\ cm^3 (cc)$

Hence **the volume units millilitre (mL) and cubic centimeter (cc) can be used interchangeably.** It may again be stated that metric symbols are not changed into plurals. Thus,

Correct	Incorrect
mL (or ml)	mLs (mls), m.l., ml.

SI UNIT OF TEMPERATURE

The series of markings on a thermometer which read temperature is called a **temperature scale.**

A temperature scale in which 0º is assigned to the freezing point of pure water and 100º to the boiling-point is known as the **Celsius scale.** The temperatures are expressed in **degrees Celsius** (ºC). **Room temperature on the celsius scale is taken to be 25° C.** The celsius scale is not a part of the SI system. Since it is widely used in scientific literature, it is difficult to abandon it.

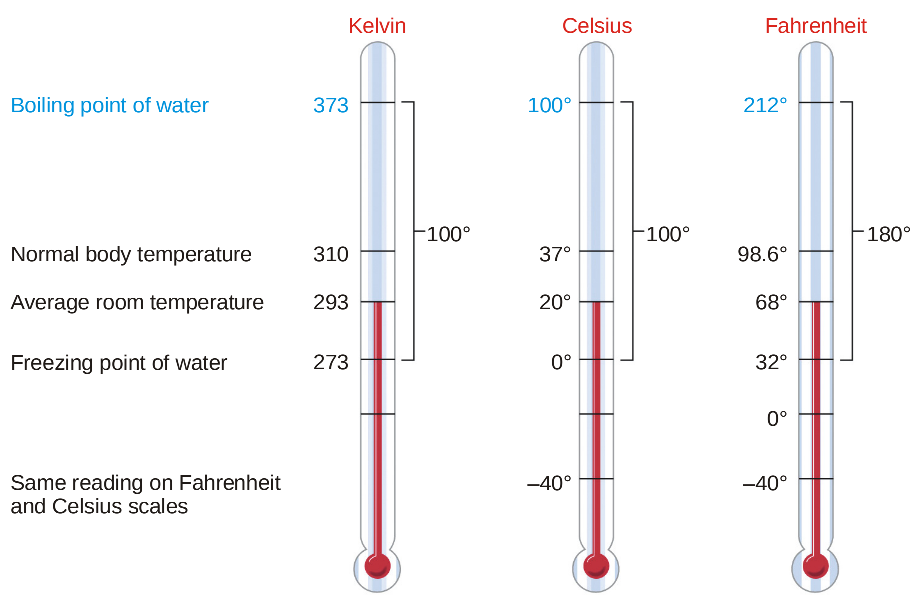
The SI system uses the Kelvin scale. A degree on the Kelvin scale has the same magnitude as a degree on the celsius scale but zero on the Kelvin scale equals – 273.15ºC. Thus the temperature (0 K) is often referred to as the **absolute zero.** Celsius and Kelvin temperature are related as

$$\mathbf{K = °C + 273.15}$$

$$\mathbf{°C = K - 273.15}$$

It may be noted that the unit for temperature on the Kelvin scale is **K and not °K.** This notation has been approved by IUPAC and is now used by chemists all over the world. **Thus it may be noted that a degree sign (°) is not used with the Kelvin scale.**

On the **Fahrenheit scale** pure water freezes at 32º and boils at 212º. Thus 100º celsius equals 212 – 32 = 180 Fahrenheit degrees. Celsius and Kelvin temperatures are related by the following equations.



■ **Figure 2**

A comparison of Kelvin, Celsius, and Fahrenheit scales.

$$^{\circ}C = \frac{5}{9}(^{\circ}F - 32)$$

$$^{\circ}F = \frac{9}{5}\,^{\circ}C + 32$$

Using these relations it is easy to convert a temperature reading from Fahrenheit to Celsius and *vice versa*.

UNITS OF MASS AND WEIGHT

A beginner is apt to confuse mass with weight. The two quantities are related but are not equal. The **mass** (m) of an object is the amount of matter contained in that object. Mass is an invariant property of an object. It is the same on the surface of the earth as on the surface of the moon.

The **weight** (w), on the other hand, is force and not mass. It can be calculated by multiplying mass with the gravitational acceleration (g). That is,

$$\boldsymbol{w = m \times g}$$

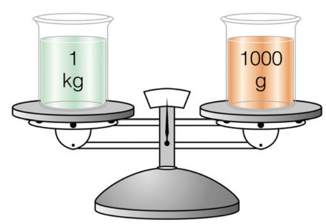
The gravitational pull on an object decreases as the object is moved farther from the centre of the earth. Thus astronauts lose weight as they move higher and higher from earth. It follows, therefore, that **even though the weight of an object can vary at different places, its mass stays the same.**

Although mass and weight are not the same, the two terms are used interchangeably even by the scientific community. This is so because an object of a certain mass weigh with virtually the same anywhere on the earth. Known masses, for example, are measured by a process termed 'weighing' with a balance.

The basic unit of mass in the metric system (or SI system) is gram. The commonly used units based on the gram are listed in Table 3.

TABLE 3. COMMONLY USED METRIC WEIGHT AND MASS UNITS

Unit	Symbol	In terms of grams
gram	g	
Kilogram	kg	1 kg = 10^3 g
milligram	mg	1 mg = 10^{-3} g
microgram	µg	1 µg = 10^{-6} g



The British system of metric weights is also used by chemists in which

ounce (1 1b = 16 oz)	1 lb = 453.6 g
pound 1 lb	2.205 lb = 1kg
ton (1 ton = 2000 lb)	

It may be noted that metric units are not pluralised. Thus,

Correct	Incorrect
2 g	2gs, 2gms, 2g.m.

UNITS OF FORCE

Force (F) is defined as the product of mass (m) and acceleration (a).

$$F = m \times a$$

Acceleration is the change in velocity (v) per unit time (t). Velocity is the change in distance (l) per unit time. Using SI base units, we can derive the unit for acceleration.

		UNIT
distance	l	m
velocity $\left(\frac{\text{distance}}{\text{time}}\right)$	v	$\frac{m}{s}$
acceleration $\left(\frac{\text{change in velocity}}{\text{time}}.\right)$	a	$\frac{m}{s^2}$

The derived SI unit for force, then, is kg ms^{-2}. The unit is called **newton** and has the symbol N. Thus,

$$1\text{ N} = 1\text{ kg ms}^{-2}$$

UNITS OF WORK AND HEAT ENERGY

Work has been defined as the product of the force and the distance through which it operates

$$w = f \times d$$

Because force is expressed in newtons and distance in meters, **the SI units of work and energy is the newton-meter.** It is also called **Joule (J).**

$$1\text{ J} = 1\text{ Nm}$$

Heat is energy that flows from one object to another because of a temperature difference between the objects. The quantity of heat transferred is best expressed in joules. But it is often given in **calories (cal).** One calorie is defined as exactly 4.184 joules. Thus,

$$1\text{ cal} = 4.184\text{ J}$$

One calorie of energy will raise the temperature of 1 g of liquid water by 1°C. *The calorie is a non-SI unit, but like the joule it can be used for any form of energy.* The calorie written with a capital C is equal to one kilocalorie, 1000 calories. Thus,

$$1\text{ C} = 1000\text{ cal}$$

UNITS OF PRESSURE

Pressure is defined as the force per unit area exerted on a surface. That is,

$$P = \frac{F}{A}$$

Thus we can determine the SI unit for pressure as :

	UNIT
Force F	kg ms^{-2} or N
Area A	m^2
Pressure $\frac{P}{A}$	kg m^{-1} s^{-2} or **Nm^{-2}**

The SI unit Nm^{-2} is named **pascal** and given the symbol **Pa.**

Three other units which have been traditionally used are :

atmosphere, symbol **atm,** is defined as the pressure exerted by a column of mercury 760 mm in height at 0ºC.

torr, symbol **Torr,** is defined as the pressure exerted by a 1 mm column of mercury at 0ºC.

millimeter of mercury or mm Hg, which is the height in millimeters of mercury that the pressure can support.

The various units of pressure are related as

$$\mathbf{1\ atm = 760\ Torr = 76\ mm\ Hg = 1.013 \times 10^5\ Pa}$$

The three non-SI units *viz.*, Torr and mm Hg are still commonly used in current practice and it will take quite some time before the scientific community adopts the SI unit Pa.

UNITS OF DENSITY

One of the physical properties of a solid, a liquid, or a gas is its density (*d*). **Density is defined as mass per unit volume.** This may be expressed mathematically as

$$d = \frac{m}{V}$$

By using the base SI units and remembering that the unit for volume is m^3, we can derive the SI unit for density.

$$\mathbf{\frac{kg}{m^3} \quad or \quad kg\ m^{-3}}$$

The other units of density commonly used are

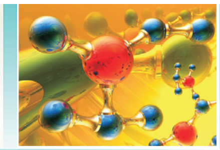
$$g\ cm^{-3} \ \text{ or } \ g\ ml^{-1} \text{ for liquid or solid densities}$$

$$g\ L^{-1} \ \text{ or } \ g\ dm^{-3} \text{ for gas densities}$$

The term **specific gravity is the ratio of the density of a substance to the density of a reference substance.** The reference substance for solids and liquids is usually water.

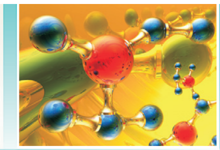
$$\text{sp gr} = \frac{\text{density of a substance}}{\text{density of reference substance}}$$

Specific gravity, being the ratio of two densities has no units.



Physical Constants

Quantity	Symbol	Traditional units	SI units
Atomic mass unit ($\frac{1}{12}$th mass of ^{12}C atom)	amu	1.6606×10^{-2} g	1.6606×10^{-27} kg
Avogadro's number	N	6.022×10^{23}	6.022×10^{23} particles/mol particles/mol
Bohr radius	a_0	0.52918 Å	5.2918×10^{-13} m
Boltzmann constant	k	1.3807×10^{-16} erg/K	1.3807×10^{-23} J/K
Charge-to-mass ratio of electron	e/m	1.7588×10^{8} Coulomb/g	1.7588×10^{11} C/kg
Electron rest mass	m_e	9.1095×10^{-28} g	9.1095×10^{-31} kg 0.00054859 amu
Faraday constant	F	96,487 coulombs/mole^{-1}	96,487 J/V mol^{-1}
Gas constant	R	$0.08206 \dfrac{\text{L atm}}{\text{mol K}}$	$8.3145 \dfrac{\text{Pa dm}^3}{\text{mol K}}$
Gravitational acceleration	g	980.6 cm/s	9.906 m/s
Molar volume (STP)	V_m	22.414 L/mol	22.414×10^{-3} m^3/mol
Neutron rest mass	m_n	1.67495×10^{-24} g	1.67495×10^{-27} kg 1.008665 amu
Planck's constant	h	6.6262×10^{-27} erg sec	6.6262×10^{-27}
Proton rest mass	m_p	1.6726×10^{-27} erg sec	1.6726×10^{-27} kg 1.0077277 amu
Velocity of ligh (in vaccum)	c	2.9979×10^{10} cm/s 186,281 miles/s	2.9979×10^{8} m/s
Rydberg constant	R_z	3.289×101^{5} cycles/s 2.1799×10^{-11} erg	1.0974×10^{7} m^{-1} 2.1799×10^{-18} J



Conversion Factors

cm → in $\quad \frac{1\text{ in}}{2.54\text{ cm}}$

cm^3 → in^3 $\quad \frac{1\text{ in}^3}{2.54\text{ cm}^3}$

cm → in → ft $\quad \frac{1\text{ in}}{2.54\text{ cm}} \quad \frac{1\text{ ft}}{12\text{ in}}$

in → cm $\quad \frac{2.54\text{ cm}}{1\text{ in}}$

in^2 → cm^2 $\quad \frac{(2.54\text{ cm})^2}{(1\text{ in})^2}$

km^2 → m^2 $\quad \frac{(1000)^2}{(1\text{ km})^2}$

km → mi $\quad \frac{0.6214\text{ m}}{1\text{ km}}$

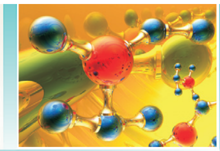
km → mi → laps $\quad \frac{0.6214\text{ mi}}{1\text{ km}} \quad \frac{1\text{ lap}}{0.250\text{ mi}}$

m → mm $\quad \frac{1\text{ mm}}{0.001\text{ m}}$

ft → in → m $\quad \frac{12\text{ in}}{1\text{ ft}} \quad \frac{1\text{ m}}{39.37\text{ in}}$

in → cm $\quad \frac{2.54\text{ cm}}{1\text{ in}}$

dm^3 → m^3 → cm^3 → in^3 $\quad \frac{(0.1\text{ m})^3}{(1\text{ dm})^3} \quad \frac{(1\text{ cm})^3}{(0.01\text{ m})^3} \quad \frac{(1\text{ in})^3}{(2.54\text{ cm})^3}$



L → qt → cu

$$\frac{1.057\ \text{qt}}{1\ \text{L}} \qquad \frac{4\ \text{cu}}{1\ \text{qt}}$$

g → mL → L

$$\frac{1\ \text{mL}}{0.84\ \text{g}} \qquad \frac{1\ \text{L}}{1000\ \text{mL}}$$

g → cm^3 → mL

$$\frac{1\ \text{cm}^3}{1.32\ \text{g}} \qquad \frac{1\ \text{mL}}{1\ \text{cm}^3}$$

kg → g → cm^3

$$\frac{1000\ \text{g}}{1\ \text{kg}} \qquad \frac{1\ \text{cm}^3}{0.752}$$

kg → g → cm^3 → mL → L

$$\frac{1000\ \text{g}}{1\ \text{kg}} \qquad \frac{1\ \text{cm}^3}{0.789\text{g}} \qquad \frac{1\ \text{mL}}{1\text{cm}^3} \qquad \frac{1\ \text{L}}{100\ \text{mL}}$$

K → °C $\quad$ K = °C + 273

°C → K $\quad$ K = °C + 273

°F → °C $\quad$ $°C = \frac{[°F - 32]}{1.8}$

°C → °F $\quad$ $°C = \frac{[°F - 32]}{1.8}$

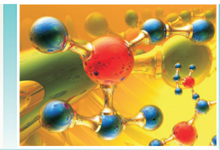
K → °C → °F

K = °C + 273 $\qquad$ $°C = \frac{[°F - 32]}{1.8}$

m, V → d $\quad$ $d = \frac{m}{v}$

Cal → cal → J

$$\frac{1000\ \text{cal}}{1\ \text{Cal}} \qquad \frac{4.184\text{J}}{1\ \text{cal}}$$



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