SOME BASIC CONCEPTS OF CHEMISTRY
UNCERTAINTY IN MEASUREMENT

❖ MEASUREMENT IN CHEMISTRY:
FUNDAMENTAL AN. D DERIVED UNITS

Chemistry is an experimental science. An experiment always involves observation-of a· phenomenon under certain set of conditions. The quantitative scientific observation generally requires the measurement of one or more physical quantities such as mass, length, density, volume, pressure, temperature, etc. A physical quantity is expressed in terms of a number and a unit. Without mentioning the unit, the number has no meaning. For example, the distance between two points is "four" has no meaning unless a specific unit (inch, centimeter, meter, etc.,) is associated with the number. The units of physical quantities depend on three basic units, i.e., units of mass, length and time. Since, these are independent units and cannot be derived from any other units, they are called fundamental units. It was soon realized that the three fundamental units cannot describe all the physical quantities such as temperature, intensity of luminosity, electric current and the amount of the. substance. Thus, seven units of measurement, namely mass, length, time, temperature, electric current, luminous intensity and amount of substance are taken as basic units. All other units can be derived from them and are, therefore, called derived units. The units of area, volume, force, work, density, velocity, energy, etc., are all derived units.

SI Units of Measurement :

Various systems of units were in use prior to 1960.The common ones are the following:

(i) The English or FPS system: The system uses the foot, the pound and the second for length, mass and time measurements respectively. It is not used now-a-days.

(ii) MKS system: Here M stands for meter (a unit of length), K for kilogram (a unit of mass) and S for second (a unit of time). This is a decimal system. .

(iii) CGS system: Here the unit of length is centimeter, the unit of mass is gram and the unit of time is second. It is also a decimal system.

MKS system often known as metric system was very popular throughout the world, but the drawback with this system was that a number of different metric units for the same quantity were used in different parts of the world. In 1964, the National Bureau of Standards adopted a slightly modified version of the metric system, which had been officially recommended in 1960 by an international body, General Conference of Weights and Measures. This revised set of units is known as the International System of Units (abbreviated SI). Now the SI units have been accepted by the scientists all over the world in all branches of science, engineering and technology. 'The SI system have seven basic units.

The various fundamental quantities that are expressed by these units along with their symbols are tabulated below:

Basic physical quantity	**Unit**	**Symbol**
Length	Meter	M
Mass	Kilogram	Kg
Time	Second	S
Temperature	Kelvin	K
Electric current	Ampere	Amp or A
Luminous intensity	Candela	Cd
Amount of substance	Mole	Mol

Sometimes, submultiples and multiples are used to reduce or enlarge the size of the different units. The names and symbols of sub-multiples and multiples are listed in the table given below. The name for the base unit for mass, the kilogram, already contains a prefix. The names of other units of mass are obtained by substituting other prefixes for prefix kilo. The names of no other base units contain prefixes.

The use of SI system is slowly growing; however, older systems are still in use. Furthermore, the existence of older units in scientific literature demands that one must be familiar with both old and new systems.

Submultiples			**Submultiples**		
Prefix	**Symbol**	**Sub-multiple**	**Prefix**	**Symbol**	**Sub-multiple**
deci	d	10^{-1}	deca	da	10
centi	c	10^{-2}	hecto	h	10^{2}
milli	m	10^{-3}	kilo	k	10^{3}
micro	µ	10^{-6}	mega	m	10^{6}
nano	n	10^{-9}	giga	g	10^{9}
Pico	p	10^{-12}	tera	t	10^{12}
femto	f	10^{-15}	peta	p	10^{15}
atto	a	10^{-18}	exa	e	10^{18}
zepto	z	10^{-21}	zeta	z	10^{21}
yocto	y	10^{-24}	yotta	y	10^{24}
Greek Alphabets					
Alpha	A	α	Nu	N	ν
Beta	B	β	Xi	≡	ξ
Gamma	R	γ	Omicron	o	o

Delta	Δ	δ	Pi	π	π
Epsilon	Ε	ε	Rho	ρ	ρ
Zeta	Ζ	ζ	Sigma	∑	σ
Eta	Η	η	Tau	τ	τ

Greek Alphabets

Theta	Θ	Θ	Upsilon	Υ	υ
Iota	Ι	τ	Phi	Φ	ϕ
Kappa	Κ	k	Chi	Χ	Ζ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	Μ	μ	Omega	Ω	ω

Numerical Prefix

Prefix	Value	Prefix	Value
Hemi	(1/2)	Deca	10
Mono	1	Undeca	11
Sesqui	$1\frac{1}{2}$	Dodeca	12
Di or Bi	2	Trideca	13
Tri	3	Tetradeca	14
Tetra	4	Pentadeca	15
Penta	5	Hexadeca	16
Hexa	6	Heptadeca	17
Hepta	7	Octadeca	18
Octa	8	Nonadeca	19
Nona	9	Eicosa	20

SI Units for Some Common Derived Quantities

(a) Area $=$ length $\times$ breadth

$= \mathrm{m} \times \mathrm{m} = \mathrm{m}^2$ [square metre]

Volume $=$ length $\times$ breadth $\times$ beight

$= \mathrm{m} \times \mathrm{m} \times \mathrm{m} = \mathrm{m}^3$ [cubic metre]

(b) Density $= \frac{\text{mass}}{\text{volume}} = \frac{\text{kg}}{\text{m}^3} = \text{kg m}^{-3}$

(c) Speed $= \frac{\text{distance covered}}{\text{time}} = \frac{\text{metre}}{\text{time}} = \text{ms}^{-1}$

(d) Aoceleration $= \frac{\text{change in velocity}}{\text{time taken}} = \frac{\text{ms}^{-1}}{\text{s}} = \text{ms}^{-2}$

(e) Force $=$ mass $\times$ acceleration

$= \text{kg} \times \text{ms}^{-2}$

$= \text{kg ms}^{-2}$ (Newton; abbreviated as N)

(f) Pressure = force per unit area

$$= \frac{\text{kg ms}^{-2}}{\text{m}^2} = \text{kg m}^{-1}\ \text{S}^{-2} \text{ or } \text{Nm}^{-2} \quad (\text{Pascal Pa})$$

(g) Energy = force $\times$ distance travelled

$$= \text{kg ms}^{-2} \times \text{m}$$

$$= \text{kg m}^2\text{S}^{-2} \qquad (\text{joule} - \text{J})$$

Some Old Units Stili in Use The use of some of the old units is still permitted. The 'liter', for example, which is defined as I cubic decimeter is used frequently by chemists. Certain other units which are not a part of SI units are still retained for a limited period of time. The term atmosphere (atm), the unit of pressure, falls into this category.

Few of the old units along with conversion factors are given below:

Length: The interatomic distances are reported in units of angstrom (A), nanometer (nm) or picometre (pm).

$$1\ \text{Å} = 10^{-8}\ \text{cm} = 10^{-10}\ \text{m}$$
$$1\text{nm} = 10^{-7}\ \text{cm} = 10^{-9}\ \text{m} = 10\text{Å}$$
$$1\text{pm} = 10^{-10}\ \text{cm} = 10^{-12}\ \text{m} = 10^{-2}\ \text{Å}$$
$$\text{nm} = 10^{3}\text{pm}$$

Mass: The basic unit of mass is generally taken as gram (g). The gram is 10-3 kg

$$1 \text{ kilogram (kg)} = 10^3\ \text{g}$$

$$1 \text{ milligram (mg)} = 10^{-3}\ \text{g}$$

$$1 \text{ microgram } (\mu_g) = 10^{-6}\ \text{g}$$

While dealing with atoms arid molecules, the term atomic mass unit (amu) is used. One amu is taken exactly as 1/12 of the. 12 masses fan atom of the carbon isotope,

CI^2: 1amu= 1.6605 x 10^{-24} g = 1.6605 X10-27 kg

Volume: The units of volume are reported as cubic centimeter (cm^3) and cubic decimeter (dm^3). Cubic decimeter is termed liter while cubic centimeter is termed milliliter.

$$1 \text{ litre (lit or L)} = (10\ \text{cm})^3 = 1000\ \text{cm}^3 = 10^{-3}\ \text{m}^3$$

$$\text{I millilitre (mL)} = (1\ \text{cm})^3 = 1\ \text{cm}^3 (\text{cc}) = 10^{-6}\ \text{m}^3$$

So, $\text{liter} = 1000\ \text{mL}$

Temperature: The Celsius temperature scale which is not a part of SI system, is ·employed in scientific studies. This scale is based on the assignment of O°C to the normal freezing point of water and 100°C to the normal boiling point of water. The celsius scale was formerly called the centigrade scale.

The unit of temperature in SI system is Kelvin. A degree on the kelvin scale has the same magnitude as the degree on the celsius scale but zero on the kelvin scale is equal to -273.15"C. The temperature (0 K) is often referred to as absolute zero.

So, or $K = : (°c + 273.15)$

$°C = \quad (K - 273.15)$

There is another important temperature scale known as Fahrenheit scale. In this scale, the normal freezing point of water is 32°F and normal boiling point is 212 °F. Thus, 100°c equals 180 °F. Both the scales are related by the following equations:

$^\circ C = \frac{5}{9} \times (\quad ^\circ F - 32)$ [since, 100 parts on celsius scale = 180 parts on Fahrenheit scale]

$^\circ F = \frac{9}{5} \times (\quad ^\circ C) + 32$

Pressure

There are three non-S1 units for pressure which are commonly used.

(a) Atmosphere (atm) is defined as the pressure exerted by a column of mercury of 760 mm or 76 cm height at O°C.

(b) Torr is defined as the pressure exerted by a 1mm column of mercury at O°C.

(c) Millimetre of mercury (mm Hg). These three units are related as:

$$1 \text{ atm} = 760 \text{ torr } - 760 \text{ mmHg} = 76\text{cm Hg} = 1.013 \times 10^5 \text{ Pa}$$

Energy: Calorie has been used in the past as a unit of energy measurement. The calorie was defamed as the. amount of heat required to raise the temperature of one gram of water from 14.5"C to 15.5°C. One calorie is defined as exactly equal to 4.184 joules.

$$\text{lcal} = 4.184 \text{ J or } 1 \text{ J} = 0.2390\text{cal}$$

$$\text{Ikcal} = 1000\text{cal} = 4.184 \text{ kJ}$$

Conversion Factors:

$1 \text{ angstrom (Å)} = 10^{-8} \text{ cm} = 10^{-10} \text{ m} = 10^{-1} \text{ nm} = 10^2 \text{pm}$

$1 \text{ inch} = 2.54 \text{ cm}$ or $1\text{cm} = 0.394 \text{ inch}$

$39.37 \text{ inch} = 1 \text{ metre}$ $1\text{km} = 0.621\text{mile}$

$1\text{kg} = 2.20 \text{ pounds (lb)}$ $1\text{g} = 0.0353 \text{ ounce (o)}$

$1 \text{ pound (lb)} = 453.6 \text{ g}$

$1 \text{ atomic mass unit (amu)} = 1.6605 \times 10^{-24} \text{ g}$

$= 1.6605 \times 10^{-27} kg$

$= 1.492 \times 10^{-3}$erg $= 1.492 \times 10^{-10}$J

$= 3.564 \times 10^{11}$cal $= 9.310 \times 10^{8}$eV

$= 931.48$MeV

I atmosphere (atm) $= 760$ torr $-$ 760mm Hg $-$ 76cm Hg

$= 1.01325 \times 10^{5}$ Pa

Icalorie (cal) $= 4.1840 \times 10^{7}$erg $= 4.184$ J

$= 2.613 \times 10^{19} eV$

1 coulomb (coul) $= 2.9979 \times 10^{9}$ esu

1curie (Ci) $= 3.7 \times 10^{10}$ disintegrations sec^{-1}

lelectron volt (eV) $= 1.6021 \times 10^{-12}$ erg $= 1.6021 \times 10^{-19}$ J

$= 3.827 \times 10^{-20}$cal

$= 23.06$kcalmol^{-1}

1erg $= 10^{-7}$ J $= 2.389 \times 10^{-8}$cal $= 6.242 \times 10^{11}$eV

1 $electrostatic\ unit\ (esu)$ $= 3.33564 \times 10^{-10}$ coul

1 $faraday$ (F) $= 9.6487 \times 10^{4}$ coul

1 dyme (dyne) $= 10^{-5}$ N coul

1 joule $= 10^{7}$erg $= 0.2390$cal

1 litre $= 1000$ce $= 1000$ mL $-$ 1dm^{3}

$= 10^{-3}$ m^{3}

Values of Some Useful Constants

Fundamental constant	Valne in old enits	Value in SI units
"Avogadro"' number (N)	6.023×10^{23} mol^{-1}	6.023×10^{23} mol^{-1}
Atomie mass unit (amu)	1.6605×10^{-24} g	1.6605×10^{-24} g
Bohr radius (α_0)	0.52918 A $= 0.52918 \times 10^{-8}$cm	5.2918×10^{-11} m
Boltrmame constant (k)	1.3807×10^{-14}ergdeg^{-1}	1.3807×10^{-23}JK^{-1}
Charge on electron (e)	(-)4.8029×10^{-16} eau	$(-)1.6021 \times 10^{-19}$ coul
Change to mass ratio e/ m Of electron	1.7588×10^{8} coul g^{-1}	1.7588×10^{11}coul kg^{-1}.
Electron restmass(m_ϵ)	9.1091×10^{-28}g	9.1091×10^{-31} kg

Gas constant (R)	0.0821 lit atm deg^{-1} mol^{-1} 8.314×10^{7} erg deg^{-1} mol^{-1} $1.987 = 2.0 cal deg^{-1}$ mol^{-1}	8.3.4 $JK^{-1} mal^{-4}$
Molar volume at NTP (V_m)	22.4 L mol^{-1}	22.4×10^{-3} m^3 mol^{-1}
Planek's constant (h)	6.6252×10^{-27} erg see	6.6252×10^{-34} J see
Proton mass (m_p)	1.6726×10^{-24} g	1.6726×10^{-27} kg
Neutron mass (m_e)	1.67495×10^{-24} g	1.67495×10^{-27} kg
Rydberg constant (R_2)	109678 cm^{-1}	1.09678×10^{7} m^{-1}
Velocity of light (c) in vacuum	2.9979×10^{10} cm sec^{-1} or 186281 miles sec^{-1}	2.9979×10^{8} m sec^{-1}
Faraday (F)	9.6487×10^{4} C/ equiv or 96500 Ciequiv	9.6487×10^{4} C/ equiv
$\frac{1}{4\pi\varepsilon_0}$	1	0.8988×10^{30} N $m^2 C^{-2}$ or 9×10^{9} N $m^2 C^{-2}$

Derived SI Units

Quantity with Symbol	Unit (SI)	Symbol
Velocity(ν)	metre per sec	ms^{-1}
Area (A)	square metre	m^2
Volume (V)	cubie metre	m^3
Density (D)	kilogram m^{-3}	kg m^{-3}
Aceelenation (a)	metre per sec	m s^{-2}
Energy (E)	joule (J)	kg m^2 s^{-2}
Force (F)	- newton (N)	kg m s^{-2}
Power (W)	watt (W)	Js^{-1}; kgm^2 s^{-3}
Pressure (P)	pascal (Pa)	Nm^{-2}
Resistance(R)	ohm (Ω)	VA^{-1}
Conduction (C)	ohm^{-1}, mho, siemens	m^{-2} kg^{-1} $s^3 A^2$ or Q^{-1}
Potential difference	volt (V)	kgm^2 $s^{-3} A^{-1}$
Electrical charge	coulomb (C)	A-s (ampere-second)
Frequency (v)	hertz (Hz)	cycle per sec
Magnetic flux $\times$ density	tesla (T)	kgs^{-2} A^{-1} $= NA^{-1}$ m^{-1}

Derived SI Units

Popular Units and their SI Equivalents

Physical quantity	Unit with symbol	Equivalent in SI unit
Mass	1amu	$1\text{amu} = 1.6605 \times 10^{-27}\text{kg}$
Energy	1 electron volt (eV)	1.602×10^{-19} joule
Length	1Å	$10^{-10}\text{m}(10^{-1}\text{nm})$
Volume	liter	$10^{-3}\ \text{m}^3 = \text{dm}^3$
Force	dyne	10^{-5} N
Pressure	1 atmosphere	760torr(760 mmHg) 101325pa or 10^5pa
	1bar	101325pa or 10^5pa
	1 torr	133.322Nm^{-2}
Dipole moment	debye, $10^{-18}\text{csu} - \text{cm}$	3.324×10^{-30}cm
Magnetic flux density	gauss (G)	10^{-4} T
Area of nuclear cross section	1 barn	$10^{-24}\ \text{m}^2$
Nuclear Diameter	1 fermi (1femto)	10^{-15}m

Significant Figures

There is always some degree of uncertainty in every scientific measurement except in counting. The uncertainty in. measurement mainly depends upon two factors:

(i) Skill and accuracy of the observer,

(ii) Limitation of the measuring scale.

To indicate the precision of a measurement, scientists use the term significant figures.

The significant figures in a number are all certain digits plus one doubtful digit. The number of significant figures gives the information that except the digit at extreme right, all other digits are precise or reproducible.

For example, mass of an object is 11.24 g. This value indicates that actual mass of the object lies between 11.23 g and 11.25 g. Thus, one is sure of feast three figures (1, 1 and 2) but the fourth figure is somewhat inexact. The total significant figures in this number are four.

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

(i) All non-zero digits are significant. For example, 42.3 has three significant figures

243.4 has four significant figures.

24.123 has five significant figures.

(ii) A zero becomes significant figure if it appears between two non-zero digits.

For example,

5.03 has three significant figures.

5.604 has four significant figures.

4.004 has four significant figures.

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

For example,

0.543 has three significant figures.

0.045 has two significant figures.

0.006 has one significant figure.

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

For example,

433.0 has four significant figures.

433.00 has five significant figures.

343.000 has six significant figures.

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

For example,

1.32 x 10-2 has three significant figures.

1.32 x 104 has three significant figures.

(vi) The non-significant figures in the measurements are rounded off.

(a) If the figure following the last number to be retained is less than 5, all the unwanted figures are discarded and the last number is left unchanged, e.g.,

5.6724 is 5.67 to three significant figures.

(b) If the figure following the last number to be retained is greater than 5, the last figure to be retained is increased by I unit and the unwanted figures are discarded, e.g.,

8.6526 is 8.653 to four significant figures.

(c) If the figure following the last number to be retained is 5, the last figure is increased by 1 only in case it happens to be odd. In case of even number the last figure remains unchanged.

2.3524 is 2.4 to two significant figures.

7.4511 is 7.4 to two significant figures.

Calculations Involving Significant Figures

In most of the experiments, the observations of various measurements are to be combined mathematically, i. e., added, subtracted, multiplied or divided as to achieve the fmal result. Since, all the observations in measurements do not have the same precision, it is natural that the final result cannot be more *precise* than the least precise measurement.

The following two rules should be followed to obtain the proper number of significant figures in any calculation.

Rule 1: The result of an addition or subtraction in the numbers having different precisions should be reported to the same number of decimal places as are present in the number having the least number of decimal places.

E.g.:

(a)

33.3 ← (has only one decimal place)
3.11
0.313
Sum 36.723 ← (answer should be reported to one decimal place)

Correct answer = 36.7

(d)

3.1421
0.241
0.09 ← (has 2 decimal places)
Sum 3.4731 ← (answer should be reported to 2 decimal places)

Correct answer = 3.47

(C)

62.831 ← (has 3 decimal places)
\- 24.5492
Difference 38.2818 ← (answer should be reported to3 decimal places after rounding off

Correct answer = 38.282

Rule 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.

e.g.:

(a)

142.06
× 000.23 ← (two significant figures)
32.6738 ← (answer should have two significant figures)

Correct answer = 33

(b)

$$\begin{array}{r} 51.028 \\ \times \ \underline{1.31\ \ } \\ \underline{66.84668} \end{array} \leftarrow \text{(three significant figures)}$$

Correct answer $= 66.8$

(c)

$$\frac{0.90}{4.26} = 0.2112676$$

Correct answer $= 0.21$