In addition to the concentration units described above, there are three other ways of expressing the concentration of a solution containing either a solid or a liquid solute, namely, molarity (M), normality (N) and molality.

Molarity (M) is defined as the number of mol of solute dissolved in 1 litre of solution.

Normality (N) is defined as the number of geq dissolved in 1 litre of solution.

Molality (mol/kg) is defined as the number of mol of solute dissolved in 1 kilogram of solvent.

From the definition of normality, it is thus possible to find the concentration of solute in g/l (a modified expression of the density).

$$\text{Concentration in g/l} = \text{normality } (N) \times \text{equivalent weight} \tag{2.11}$$

Example 2.14 A solution of caustic soda in water contains 20% NaOH (by weight) at 333 K (60°C). The density of the solution is 1.196 kg/l. Find the molarity, normality and molality of the solution.

Solution Basis: 100 kg solution of caustic soda

The solution contains 20 kg NaOH.

$$\text{Density of the solution} = 1.196 \text{ kg/l}$$

$$\text{Volume of the solution} = \frac{100}{1.196} = 83.62 \text{ l}$$

$$\text{Moles of NaOH in the solution} = \frac{20}{40} = 0.5 \text{ kmol} \equiv 500 \text{ mol}$$

$$\text{Molarity } (M) = \frac{\text{moles of solute}}{\text{volume of solution}}$$

$$= \frac{500}{83.62} = 5.98$$

For NaOH, since it is univalent,

$$\text{Molecular weight} = \text{equivalent weight}$$

Therefore,

$$\text{Normality } (N) = \text{molarity } (M) = 5.98$$

$$\text{Molality} = \frac{\text{Moles of solute}}{\text{weight of solvent}}$$

$$= \frac{500}{80} = 6.25 \text{ mol/kg}$$ *Ans.*

Example 2.15 Aqueous solution of triethanolamine (TEA), i.e., $N(CH_2CH_2OH)_3$, contains 50% TEA by weight. Find the molarity of the solution if the density of the solution is 1.05 kg/l.

Solution Basis: 100 kg TEA solution

The solution contains 50 kg TEA.

$$\text{Molecular weight of TEA} = 149$$

$$\text{Moles of TEA present in the solution} = \frac{50}{149} = 0.3356 \text{ kmol}$$

$$\text{Volume of the solution} = \frac{100}{1.05} = 95.24 \text{ l}$$

$$\text{Molarity of the solution} = \left(\frac{0.3356}{95.24}\right) \times 1000 = 3.524\ M \qquad \textit{Ans.}$$

The solubility of a gas in a liquid or solution is expressed in different ways. Some common ways of expression are weight %, mole %, amount of volume dissolved at specific conditions and mole ratio. Any one of them can be converted into another easily.

Example 2.16 The concentration of CO_2 is measured to be 0.206 kmol per kmol monoethanolamine (MEA) in a 20% (by weight) aqueous MEA solution. Assuming the density of the solution to be nearly 1.0 kg/l, find the concentration of CO_2 as weight % and mole % in the solution.

Solution Basis: 100 kg aqueous MEA solution

The solution contains 20 kg MEA.

$$\text{Chemical formula of MEA} = NH_2CH_2CH_2OH$$

$$\text{Molecular weight of MEA} = 61$$

$$\text{Moles of MEA in the solution} = \frac{20}{61} = 0.3279 \text{ kmol}$$

$$CO_2 \text{ dissolved in the solution} = 0.206 \times 0.3279 = 0.0675 \text{ kmol}$$

$$\text{Weight of } CO_2 = 0.06754 \times 44 = 2.973 \text{ kg}$$

$$\text{Moles of water} = \frac{(100 - 22.973)}{18} = 4.2793 \text{ kmol}$$

Table 2.1 Composition of Lean MEA

Component	kmol n_i	Mole %	Molecular weight M_i	Weight kg $(n_i.M_i)$	Weight %
Water	4.2793	91.54	18	77.027	77.03
MEA	0.3279	7.02	61	20	20.00
CO_2	0.0675	1.44	44	2.973	2.97
Total	4.6747	100.00		100.00	100.00

2.25) An aqueous solution of DAPOL — diamino - iso - propanol $[C_3H_4OH(NH_2)_2]$ contains 24.5 % DAPOL (by weight). Convert the concentration into molality assuming the density of the solution as 1.04 kg/l.

Molarity = Mole / lit.

Basis: ~~1 lit of solution~~
100 kg solution.

contains 24.5 kg DAPOL.

$$\text{volume of solution} = \frac{\overset{5}{\cancel{100}}\ kg}{\underset{52}{\cancel{1040}}\ kg/m^3}$$

$= 0.0961\ m^3$.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

52) 500 (0.0961
468
320
312

1.04 kg/l
1040 kg/m3.

Molecular weight of DAPOL = 89 kg/kmol.

$3C = 3C = 36$

$H_4 + H + H_4 = 9H$ 09

O = 0   16

N_2 = 2N   28

89

64
7 2

890) 2750 (0.308
2670
008000
7120
8800

moles of Dapol = $\frac{27.5}{89}$

= 0.308 kmoles.

0.0961 m^3 —— 0.308 kmol

1 m^3 — ?

$\frac{1 \times 0.308}{0.0961}$

3.123 M

2+32+64=98

(2.26) Make the following conversions.

(a) 294 g/l H_2SO_4 to normality.

Molecular weight of H_2SO_4 = 98

valency of H_2SO_4 = 2

Equivalent weight of H_2SO_4 = $\frac{98}{2}$ = 49

49) 294 (6
294
49

5
24

Normality = 6 N.

(b) 4.8 mg/ml $CaCl_2$ to normality.

40
35.5
35.5
~~71.0~~
111.0

Molecular weight of $CaCl_2$ = 111 kg/kmol

Equivalent weight of $CaCl_2$ = $\frac{111}{2}$ = 55.5 g equivalent

4.8 mg / ml

or 4.8 g / lit.

555) 4800 (0.08
~~4995~~
4440
3600
3330
2700
2775

55.5 g —— 1.

4.8 g —— $\frac{4.8}{55.5}$

~~0.8649 N~~   0.086 N

(2.21) (c) 5 N H_3PO_4 to g/l.

Molecular weight of phosphoric acid
$3+31+64 = \cancel{128}\ 98$ kg / kmol

valency of H_3PO_4 = 3.

Equivalent weight of H_3PO_4 = $\frac{\cancel{128}\ 98}{3} = \cancel{42.66}\ 32.66$

$\frac{\cancel{42.66 \times 5}}{\cancel{213.30}}$ $\frac{32.66 \times 5}{163.30}$ $\frac{3}{1}$

Ans: $\underline{163.3\ g/lit.}$

(d) 54.75 g/l HCl to molarity.

~~Mol. wt of HCl = 36.5 kg/kmol.~~
~~valency of HCl = 1~~

~~g equi~~
~~Equivalent weight of HCl = $\frac{36.5}{1}$ = 36.5 g Equivalent~~

moles of HCl = $\frac{54.75}{36.5}$

$\underline{1.5\ M}$

3650) 5475 (1.5
3650
18250
18250

(e) 3M K_2SO_4 to g/l.

mole = $\frac{wt}{mol.\ wt}$.

Mol. wt of K_2SO_4 = 39+39+32+64 = 174 kg/kmol.

$\frac{3 \times 174}{522\ g/lit.}$ 1

(2.29) Carbon dioxide is dissolved to the extent of 38 litres per litre of solution of 27.5% (by weight) DAPOL. The volume of CO_2 gas measured at 101.325 kPa a and 288.7 K. Find the weight % and mole % of CO_2 in the solution.

STP (0°C, 1 atm)
1 mole occupies 22.4 l
NTP (20°C, 1 atm)
1 mole occupies 22 l

Basis: 1 litre of solution

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$\frac{38}{288.7} = \frac{22.7}{273}$

$\frac{38 \cancel{V_1}}{288.7} = \frac{\cancel{22} \, 22.7}{273}$

12
32
44

at STP 1 mole occupies ~~22.7~~ 22.414 litres

~~22.7~~ 22 litres ——— 1 mole

38 lit $\frac{38 \times 1}{\cancel{22.7}\ 22} = \cancel{1.674}\ 1.727$ moles

wt. of CO_2 = ~~1.674~~ 1.727 × mol. wt. of CO_2

= ~~1.674~~ 1.727 × 44

wt of CO_2 = ~~73.68~~ 76 g CO_2

27.50 g DAPOL

898.84 g water

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$\frac{\cancel{38}V_2}{288.7} = \frac{22.7}{273}$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$\frac{22.7}{\cancel{288.7}\ 273} = \frac{V_2}{288.7}$

$\frac{\cancel{22.7}}{273} = \frac{38}{288.7}$

$\frac{22.414}{273} = \frac{V_2}{288.7}$

wt. % of CO_2 = $\frac{73.65}{73.65 + 27.5 + 898.84}$

= 0.07365 × 100

= 7.365

mole % = $\frac{1.674}{1.674 + \frac{27.5}{89} + \frac{898.84}{18}} \times 100$

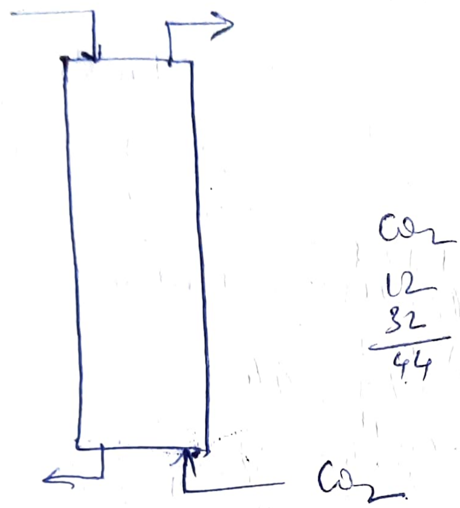
= $\frac{1.674}{1.674 + 0.308 + 49.93}$

= $\frac{1.674}{51.917}$

= 3.22 mole %

(Q-30) An aqueous solution of monoethanolamine containing 20% MEA (by weight). It is utilized for the absorption of CO_2. Rich solution from the absorber contains 40 volumes CO_2. Calculate CO_2 loading in terms of moles CO_2 dissolved per mole MEA assuming that the density of the solution is 1.011 kg/l. [Hint: 40 volume CO_2 concentration means that a litre solution will liberate 40 litres CO_2 at 101.325 kPa a and 273 K (0°C)]

Solvent
20% MEA soln



40 volumes of CO_2

1 lit — 40 lit CO_2

22.7 lit — 1 mol
40 lit — ?

$\frac{40 \times 1}{22.7}$

$= 1.762$ moles of CO_2

$= 77.533$ g of CO_2

CO_2
12
32
44

~~1 litre of solution from the absorber~~

Basis: 100 kg solution from the absorber.

~~20 kg MEA~~

100 kg soln
~~1011 kg~~ 1.011 kg/L
~~m3~~
~~= 0.0989 m3~~

$= 98.911$ lit.

12+32
= 44 kg/kmol

77.533 g of CO_2 × 98.911 Lit = 7668.949 g of CO_2

= 7.688 kg of CO_2

20.000 kg MEA
7.688 kg CO_2
72.312 kg water

K moles of MEA = $\frac{20 \text{ kg}}{61 \text{ kg/kmol}}$

= ~~0.372 kmoles~~
= 0.3278

MEA · $C_2H_5ONH_2$

24+5+16+14+2 = 61

k moles of CO_2 = $\frac{7.688 \text{ kg}}{44 \text{ kg/kmol}}$

0.583 kg moles | ~~75 kg~~ 65 Wt

~~0.583 g moles~~ | ~~75 kg~~

583 g moles | 65 Wt

$\frac{0.583}{75}$

~~75000) 5830 (0.~~

~~7.77 Molality~~

$\boxed{8.97 \text{ Molality}}$

75) 583 (7.77
525
580
525
550

(2.28) An aqueous solution of K_2CO_3 is prepared by dissolving 43 kg K_2CO_3 in 100 kg water at 293 K (20°C). The density of the solution is measured to be 1.3 kg/l. Find the molarity, normality and molality of the solution

molality

~~Molarity~~

Mole. Wt. of K_2CO_3 = 39.1
39.1
12.0
48.0
138.2

Kmole of K_2CO_3 = $\frac{43 \text{ kg}}{138.2}$

1382) 4300 (0.3111
4146
01540
1382
01580
1382
1980

Kmole of K_2CO_3 = 0.3111

~~311 moles — 100 lit.~~

100 lit — 311 moles

1 lit — ?

$\boxed{\frac{311}{100} = 3.11 \text{ M}}$

Total weight of solution = 43 + 100
= 143 kg.

volum of solution = $\frac{143}{1300}$ density = $\frac{mass}{vol}$
= 0.11 m^3

1300) 1430 (0.11
1300
01300
1300

0.11 m^3 ——— 0.3111 kmol K_2CO_3
1 m^3 ——— $\frac{0.3111}{0.11}$

110) 311 (2.82
220
0910
880
0300
220
80

$\boxed{2.82 \text{ kmol} / m^3 = M}$

Normality

~~100 kg~~ ——— ~~43 kg~~
~~1 kg or 1 lit~~ ? $\frac{43}{100}$

100) ~~430~~ (~~0.4~~
~~400~~

Molecular weight of K_2CO_3 = 138.2 kg/kmol.
Equivalent weight of K_2CO_3 = $\frac{138.2}{2}$
= 69.1 g equivalent.

~~43000 g~~
100 lit ——— 43000 g.
1 lit ——— $\frac{43000 g}{100 lit}$
430 g/lit.

691) 4300 (6.2
4146
1540
1382
01580
1382
019 80

69.1 g/lit ——— 1 N
430 g/lit ——— ? $\frac{430 \times 1}{69.1}$

$\boxed{6.22 \text{ N}}$