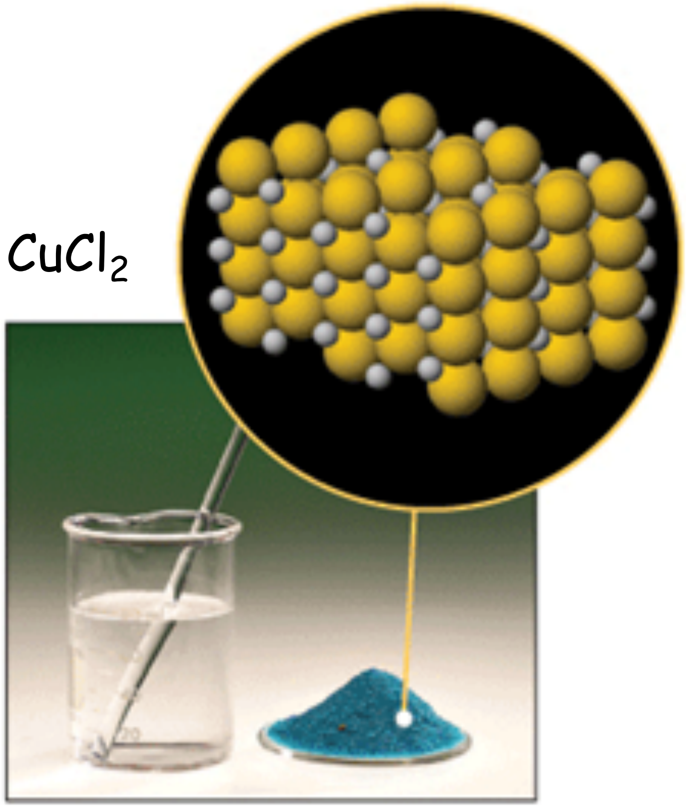
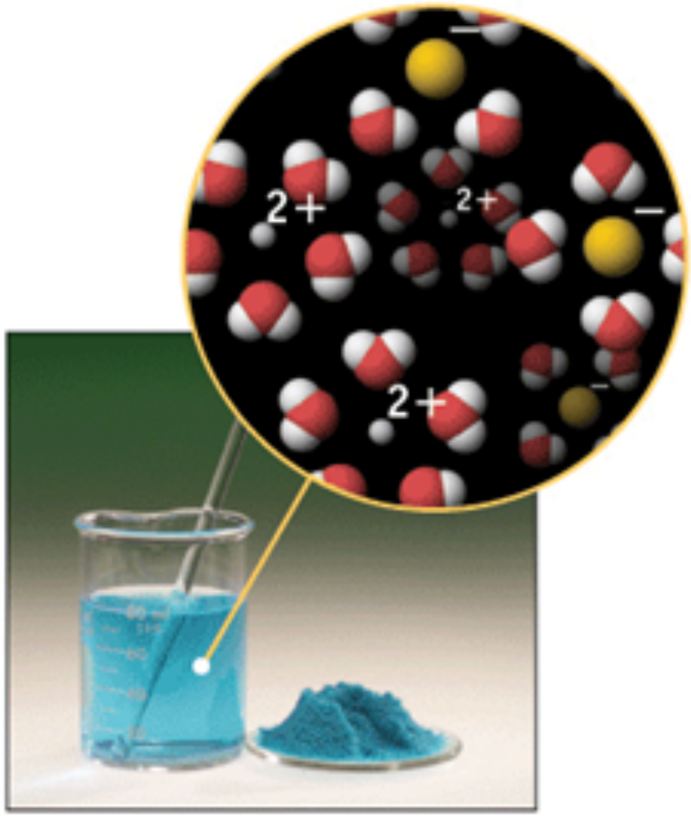
Solutions

$CuCl_2$





A solution is a homogenous mixture of two or more components (atoms, molecules, ions) in a single phase (solid, liquid or gaseous).

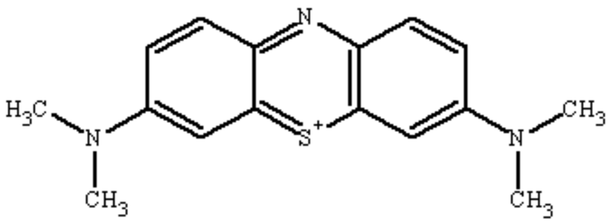
Alcune immagine sono state prese e modificate da "Chimica" di Kotz, Treichel & Weaver, Edises 2007, III edizione

- air is a gaseous solution: N_2, O_2, CO_2, H_2O (g) and other gases
- 18 K gold is a solid solution (alloy) of Au (75%) and Cu (25%)
- brass is a solid solution of Zn and Cu
- bronze is a solid solution of Sn and Cu
- gasoline is a liquid solution of octane (C_8H_{18}) and other hydrocarbons

In a homogeneous solution particles are distributed evenly and each portion of the solution has the same physical and chemical properties.

Methylene blue

In this aqueous solution of methylene blue molecules of solute are uniformly distributed in the solvent (H_2O), or the composition is constant.
The melting point, boiling point, density, viscosity, etc.. Are the same in each portion of the solution.



Some definitions

Generally the solvent is the component present in larger amount.
It can be a solid, a liquid or a gas. The solute or solutes can be solid, liquid or gaseous.

The most common solutions (liquid solutions) are characterized by a liquid solvent and solid, liquid or gaseous solutes.

The composition of a solution indicates the relative quantities of components.

The composition of a solution is defined quantitatively by the concentration.

The concentration indicates the amount of solute, a unit of weight, volume or moles, dissolved in a given volume or weight of solution or solvent.

The concentration can be expressed in physical or chemical units.

Concentration is defined as a function of the relative amounts of components and can be expressed in physical or chemical units.

Physical units

- percent composition by mass (%w)
- percent composition by volume (%V)
- percent composition by mass/volume (%w/V)

- **Mole Fraction (x)**
- Molarity (M)
- Molality (m)
- Normality (N)

Chemical units

The concentration units that contain the volume depend on temperature.

Example: 20.5 g sodium sulphate (Na_2SO_4) in 78.9 g water. Calculate the w/w %.

$$\%w_{Na_2SO_4} = \frac{w_{Na_2SO_4}}{w_{Na_2SO_4} + w_{H_2O}} 10^2 = \frac{20.5}{20.5 + 78.9} 10^2 = 20.62\%$$

Example: 1.6 g rameic chloride (II) ($CuCl_2$) and 3 g di Na bicarbonate($NaHCO_3$) in 55 gwater. Calulate the w/w %.

$$\%W_{CuCl_2} = \frac{W_{CuCl_2}}{W_{CuCl_2} + W_{NaHCO_3} + W_{H_2O}} 10^2 = \frac{1.6}{1.6 + 3 + 55} 10^2 = 2.68\%$$

$$\%W_{NaHCO_3} = \frac{W_{NaHCO_3}}{W_{CuCl_2} + W_{NaHCO_3} + W_{H_2O}} 10^2 = \frac{3.0}{1.6 + 3 + 55} 10^2 = 5.03\%$$

Percent composition by mass (%w)

The percentage by weight of a solute in a solution indicates the number of grams of solute contained in 100 g of solution. For a solution with n components we have:

$$\%w = \frac{w_i}{\sum_{i=1}^{n} w_i} 10^2$$

weight in grams of component i (numerator w_i)

Sum of the weight in grams of all components (i.e. solvent + solute) (denominator $\sum_{i=1}^{n} w_i$)

Example 1: A 10% aqueous solution of glucose by weight contains 10 g glucose and 90 g of water.

$$\%w_{\text{glucose}} = \frac{w_{\text{glucose}}}{w_{\text{glucose}} + w_{H_2O}} 10^2 = \frac{10}{10+90} 10^2 = 10\%$$

Percent composition by volume (%V) or weight (%W)

The percentage by volume of a solute in a solution indicates the milliliters of solute contained in 100 ml of solution. For a solution with n components we have:

$$\%V = \frac{V_i}{\sum_{i=1}^{n} V_i} 10^2$$

volume in ml of component i

Sum of the volume in ml of all components (i.e. solvent + solute)

Example : mix 110 mL of ethanol (C_2H_5OH) with 890 mL of water. Calculate the percentage by volume of ethanol.

$$\%V_{C_2H_5OH} = \frac{V_{C_2H_5OH}}{V_{C_2H_5OH} + V_{H_2O}} 10^2 = \frac{110}{110 + 890} 10^2 = 11.0\%$$

Percentage in mass/volume (%w/V)

The percentage by mass / volume expresses the amount of mass in grams of solute (s) in 100 ml of solution. The temperature must be specified!

$$\%w/V = \frac{w_i}{V} 10^2$$

grams of component i

Volume of solution

Example : 10.8 g of barium hydroxide ($Ba(OH)_2$) are dissolved in water and brought to volume in a volumetric flask of 250 ml. Calculate the percentage by mass / volume of Ba hydroxide

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$$\%w/V_{Ba(OH)_2} = \frac{w_{Ba(OH)_2}}{V} 10^2 = \frac{10.8}{250} 10^2 = 4.32\%$$

Molar fraction (x)

If n_1, n_2, n_3, …, n_i are the number of moles of p components in a solution, then the molar fraction is:

$$x_i = \frac{n_i}{\sum_{i=1}^{p} n_i}$$

number of moles of component i

Sum of the number of moles of all components (solvent + solute)

The molar fraction is an adimensional number

Example: What is the molar fraction of a10 %w aqueous solution of sulfuric acid (H_2SO_4, molecular weight= 98 g/mol)?

An aqueous solution of 10 %w H_2SO4 has 10 g (equivalent to 10/98 moles) and 90 g of H_2O (equivalent to 90/18 moles):

$$x_{H_2SO_4} = \frac{n_{H_2SO_4}}{n_{H_2SO_4} + n_{H_2O}} = \frac{\frac{10}{98}}{\frac{10}{98} + \frac{90}{18}} = 0.02 \qquad e \qquad x_{H_2O} = 1 - x_{H_2SO_4} = 0.98$$

Molarity

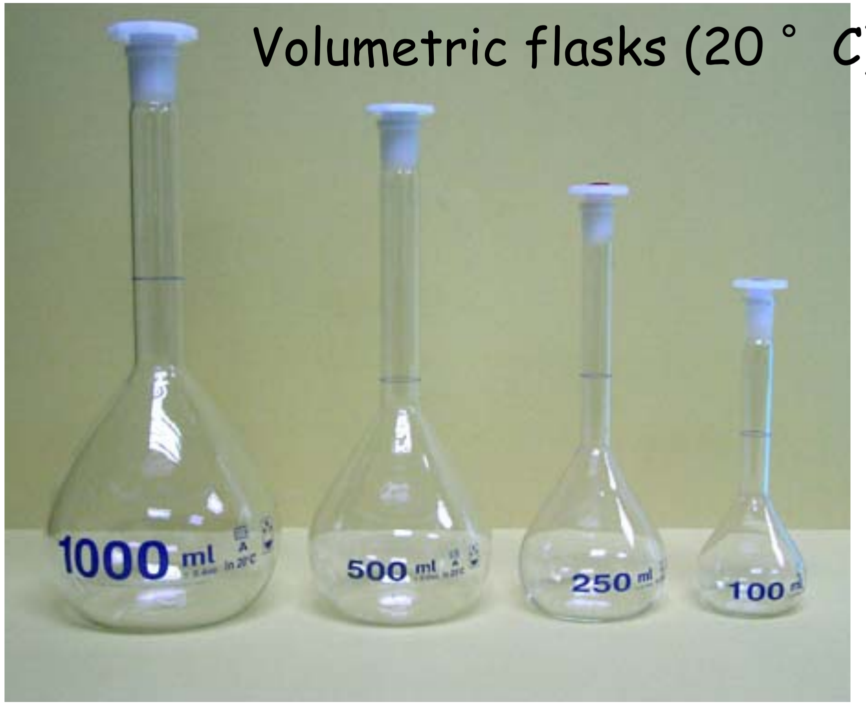
It is defined as the number of moles of solute per liter of the solution and has dimensions mole / L.

$$c_i = \frac{n_i}{V}$$

n_i: number of moles of component i

V: volume of solution

The use of this type of concentration is convenient because it is obtained by weighing the solute (or solutes), dissolving them in the solvent and bringing the solution to the final volume.



Volumetric flasks (20 ° C)

Normality

Normality is equal to the *gram equivalent weight* of a solute per liter of solution. A gram equivalent weight or equivalent is a measure of the reactive capacity of a given molecule. Normality is the only concentration unit that is reaction dependent.

$HCl \longrightarrow H^+ + Cl^-$

$NaOH \longrightarrow Na^+ + OH^-$

Monoprotic acids and bases
1 mole = 1 equivalent
M=N

$H_2SO_4 \longrightarrow 2H^+ + SO_4^{--}$

$Mg(OH)_2 \longrightarrow Mg^{++} + 2OH^-$

Diprotic acids and basis
1 mole = 2 equivalents
2M=N

$H_3PO_4 \longrightarrow 3H^+ + PO_4^{---}$

$Al(OH)_3 \longrightarrow Al^{+++} + 3OH^-$

Triprotic acids and basis
1 mole = 3 equivalents
3M=N

Solution volume and solvent volume

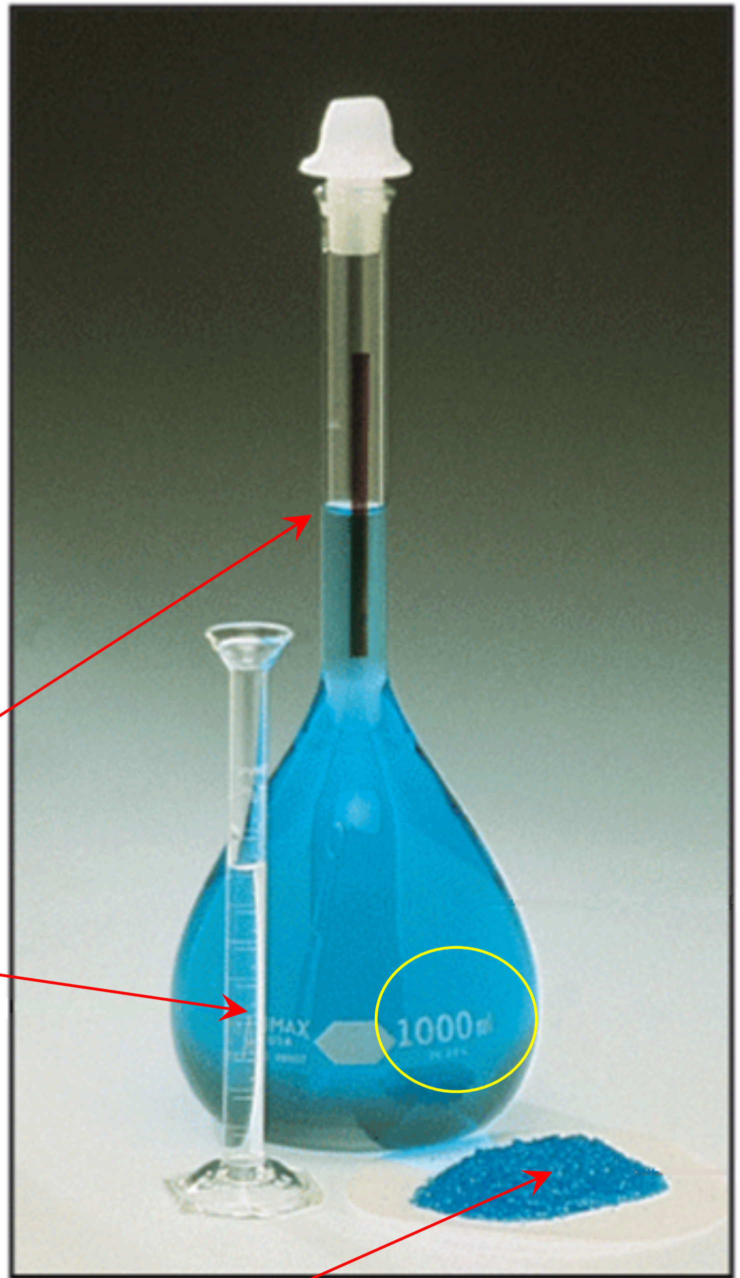
Since the density of the solution may be different from the density of pure solvent, the volume of solvent added may be higher or lower than expected!

Example: 1 litre of 0.1 M copper(II) sulphate ($CuSO_4 \cdot 5\ H_2O$, m.w.= 249.7 g/mol).

We weigh w = 0.1x249.7x1=25 g and have a final volume of 1 L

a) We introduce 25 g of solute in a 1 L flask.
b) We measure 1 L of water and pour som of it in the flask, dissolving the solute.
c) We carefully bring bring the solution to the final volume.
d) We have 8 ml left.

The density of the solution is higher than that of pure water



25 g di $CuSO_4 \cdot 5\ H_2O$

Esempio 2: A solution is prepared by dissolving 20.5 g of sodium sulphate (Na_2SO_4) in 78.9 g of water. Calculate the mass % of the salt.

$$\%w_{Na_2SO_4} = \frac{w_{Na_2SO_4}}{w_{Na_2SO_4} + w_{H_2O}} 10^2 = \frac{20.5}{20.5 + 78.9} 10^2 = 20.62\%$$

Esempio 3: A solution is prepared by dissolving 1.6 g of copper chloride ($CuCl_2$) and 3 g of sodium bicarbonate ($NaHCO_3$) in 55 g of water. Calculate the mass % of the two salts.

:

$$\%w_{CuCl_2} = \frac{w_{CuCl_2}}{w_{CuCl_2} + w_{NaHCO_3} + w_{H_2O}} 10^2 = \frac{1.6}{1.6 + 3 + 55} 10^2 = 2.68\%$$

$$\%w_{NaHCO_3} = \frac{w_{NaHCO_3}}{w_{CuCl_2} + w_{NaHCO_3} + w_{H_2O}} 10^2 = \frac{3.0}{1.6 + 3 + 55} 10^2 = 5.03\%$$

Molality

It is defined as the number of moles of solute per kg of solvent and has dimensions mole/ kg.

$$m = \frac{n_{solute}}{w_{solvent}}$$

number of moles of solute i

Amount of solvent in Kg

If the weight of solvent is expressed in g:

$$m = \frac{n_{solute}}{w_{solvent}} 10^3$$

Weight of solvent in g

Molality solutions are prepared by weighing the solutes and the solvent and since mass does not depend on temperature, it is not necessary to take it into account.

Esempio 10: What is the molality of an aqueous solution (LiCl, MW= 42.4 g/mol) prepared by dissolving 2 g of the salt in 150 g of water.

Moles of LiCl :

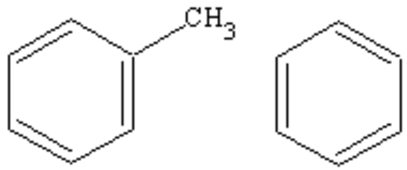
$$n_{LiCl} = \frac{w_{LiCl}}{M_{LiCl}} = \frac{2}{42.4} = 0.047 \text{ moli}$$

Therefore the molality is:

$$m = \frac{n_{LiCl}}{w_{H_2O}} 10^3 = \frac{w_{LiCl}}{M_{LiCl} w_{H_2O}} 10^3 = \frac{2}{42.4 \cdot 150} 10^3 = 0.31 \text{ m}$$

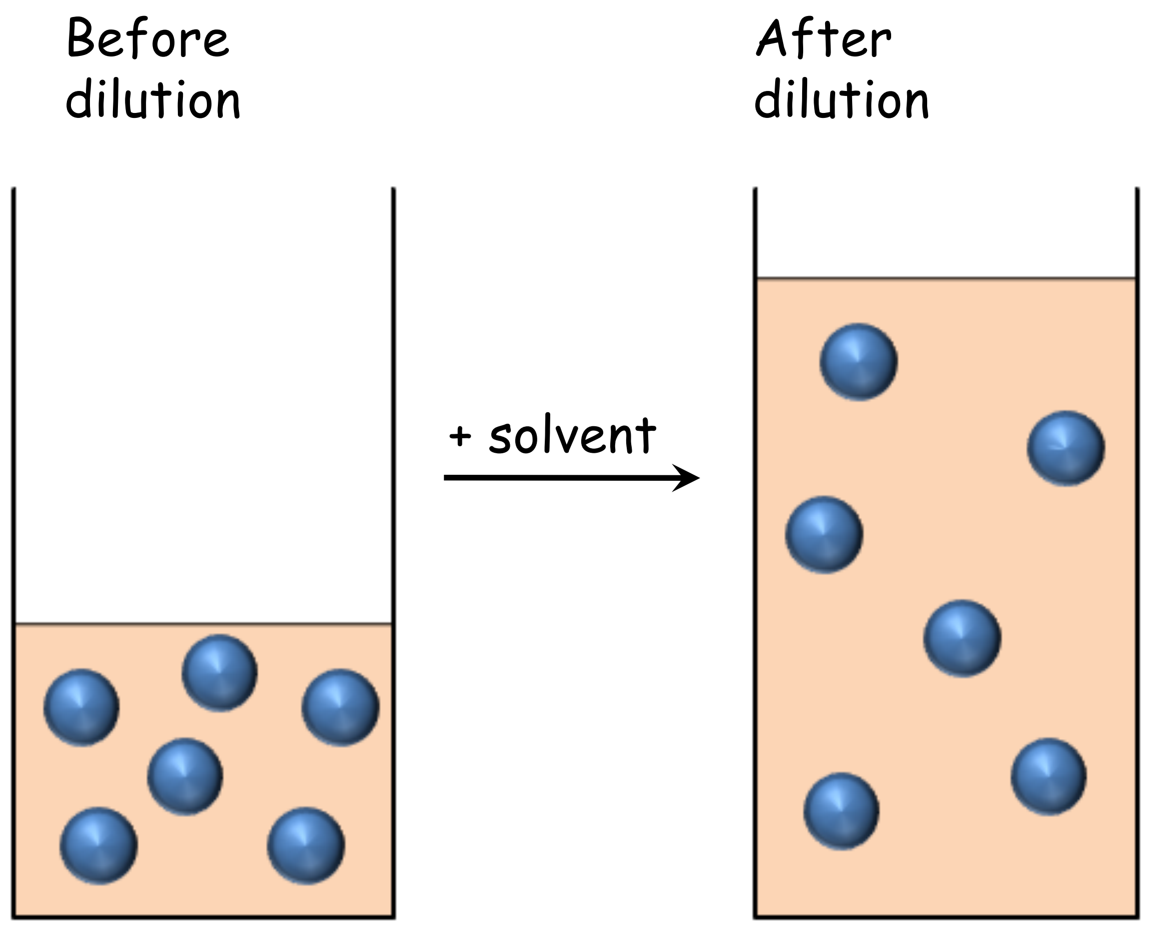
Esempio 11: A soltion is prepared by mixing 5.0 g of toluene (C_7H_8, MW = 92.14) and 225 g of benzene (C_6H_6). Calculate its molality.

Toluene is the solute and benzene is the solvent:

toluene  benzene

$$m = \frac{n_{toluene}}{w_{benzene}} 10^3 = \frac{w_{toluene}}{M_{toluene} w_{benzene}} 10^3 = \frac{5.0}{92.14 \cdot 225} 10^3 = 0.24 \text{ m}$$

In dilutions the fundamental point is that the number of moles of solute in the diluted solution must be the same than in the more concentrated one.



$$c_{initial} = \frac{n}{V_{initial}} \qquad c_{final} = \frac{n}{V_{final}}$$

Since the number of moles is constant we can write:

$$c_{initial} \cdot V_{initial} = c_{final} \cdot V_{final}$$

The product of inititial concentration and volume is equal to the product of the final concentration and volume.

The concentration of the diluted solution is obtained:

$$c_{final} = c_{initial} \frac{V_{initial}}{V_{final}}$$

Esempio 13: How many ml of water have to be added to a 300 mL water solution of NaCl 0.25 M to have a final concentration of 0.1 M?

	concentration (M)	volume (mL)
initial	0.25	300
final	0.1	?

From: $c_{iniziale} \cdot V_{iniziale} = c_{finale} \cdot V_{finale}$ si ricava:

$$V_{finale} = \frac{c_{iniziale}}{c_{finale}} \cdot V_{iniziale} = \frac{0.25}{0.1} 300 = 750 \text{ mL}$$

Since $V_{final} = V_{initial} + V_{added}$ si avrà che il $V_{added} = 400$ mL