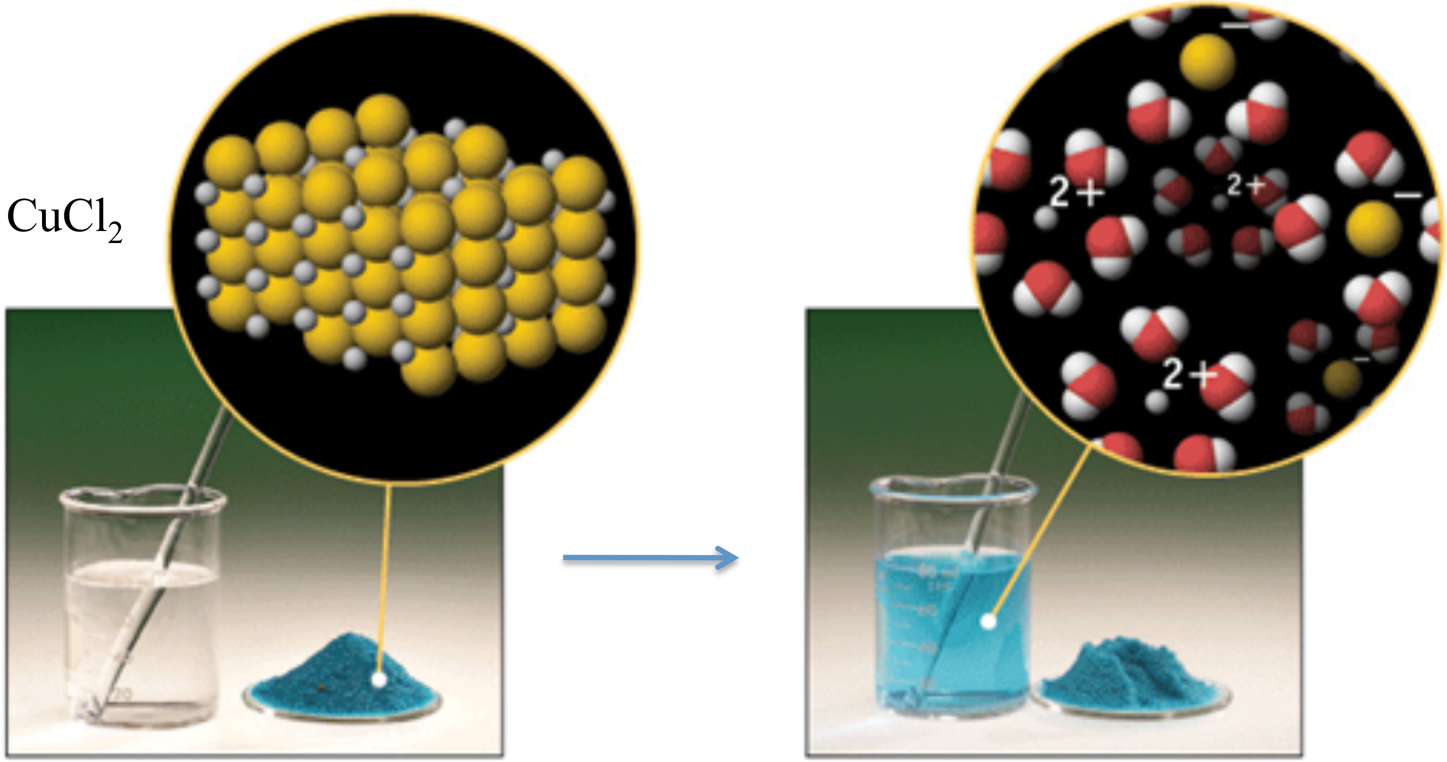
Solutions



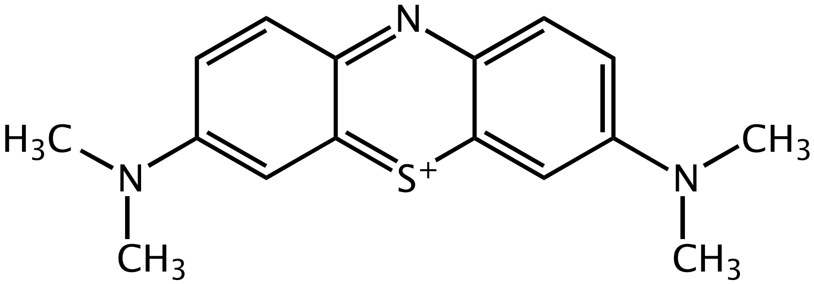
A solution is a homogenous mixture of two or more components (atoms, molecules, ions) in a single phase (solid, liquid or gaseous).

- 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

Note: the concentration units that contain the volume depend on temperature.

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

sum of the weight in grams of all components (i.e. solvent + solute)

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

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

Percent composition by volume (%V)

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.

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

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 cupric chloride ($CuCl_2$) and 3 g of sodium bicarbonate ($NaHCO_3$) in 55 g water. Caclulate the w/w %.

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

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

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 $(OH)_2$

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

Mole fraction (x)

If n_1, n_2, n_3, …, n_i are the number of moles of p components in a solution, then the mole 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 + solutes)

The mole fraction is an adimensional number

Example: What is the molar fraction of a 10 %w aqueous solution of sulfuric acid (H_2SO_4, molecular mass = 98 g/mol)?

An aqueous solution of 10 %w H_2SO_4 has 10 g (equivalent to 10/98 moles) and 90 g of H_2O (equivalent to 90/18 moles):

$$x_{H_2SO_4} = \frac{n_{H_2SO_4}}{n_{H_2SO_4} + n_{H_2O}} = \frac{\frac{10}{98}}{\frac{10}{98} + \frac{90}{18}} = 0.02$$

$$x_{H_2O} = 1 - x_{H_2SO_4} = 0.98$$

Molarity

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

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

number of moles of component i

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)

Example: If 25.3 g of sodium carbonate (Na_2CO_3) are dissolved in so much water to prepare 500 mL of solution, what is the molar concentration of Na_2CO_3 (molar mass = 106.0 g / mol)?

$$n_{mol} = \frac{\text{mass in grams}}{\text{molar mass}}$$

25.3 g of Na_2CO_3 correspond to 25.3 /106.0 = 0.239 mol of Na_2CO_3. Salt concentration is thus

$$c_{Na_2CO_3} = \frac{n_{Na_2CO_3}}{V} = \frac{w_{Na_2CO_3}}{M_{Na_2CO_3} V} = \frac{25.3}{106.0 \cdot 0.5} = 0.477 \text{ M}$$

Example: How many grams of glucose ($C_6H_{12}O_6$) should be weighed to prepare 2 L of a 0.35 M solution (molar mass = 180.16 g / mol)?

$$c_{glucosie} = \frac{n_{glucose}}{V} = \frac{w_{glucose}}{M_{glucose} V} \rightarrow w_{glucose} = c_{glucose} M_{glucose} V$$

$$w_{glucose} = 0.35 \cdot 180.16 \cdot 2 = 126.11 \text{ g}$$

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
N = M

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

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

diprotic acids and bases
1 equivalent = 2 moles
N = 2 M

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

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

triprotic acids and bases
1 equivalent = 3 moles
N = 3 M

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 L of 0.1 M copper (II) sulfate ($CuSO_4 \cdot 5\ H_2O$, m.w.= 249.7 g/mol).

1) weigh w = 0.1 x 249.7 x 1= 25 g
2) introduce 25 g of solute in a 1 L flask
3) measure 1 L of water and pour some of it in the flask, dissolving the solute
4) carefully bring the solution to the final volume.

we have 8 mL left !

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

25 g di $CuSO_4 \cdot 5\ H_2O$

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.

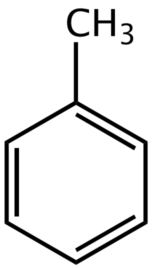
Example: Calculate the molality of an aqueous solution of lithium chloride (LiCl, molar mass = 42.4 g/mol) prepared by dissolving 2 g of the salt in 150 g of water.

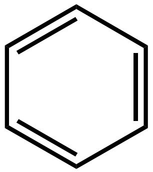
$$n_{LiCl} = \frac{w_{LiCl}}{M_{LiCl}} = \frac{2}{42.4} = 0.047 \text{ mol}$$

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

Example: A solution contains 5.0 g of toluene (C_7H_8, molar mass = 92.14 g/mol) and 225 g of benzene (C_6H_6). Calculate the molality of the solution.

toluene = solute





benzene = solvent

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

Dilution

Another method for obtaining a solution of given concentration is starting from a concentrated solution and adding solvent (dilution) until the desired concentration is reached.

0.1 M $K_2Cr_2O_7$ in H_2O

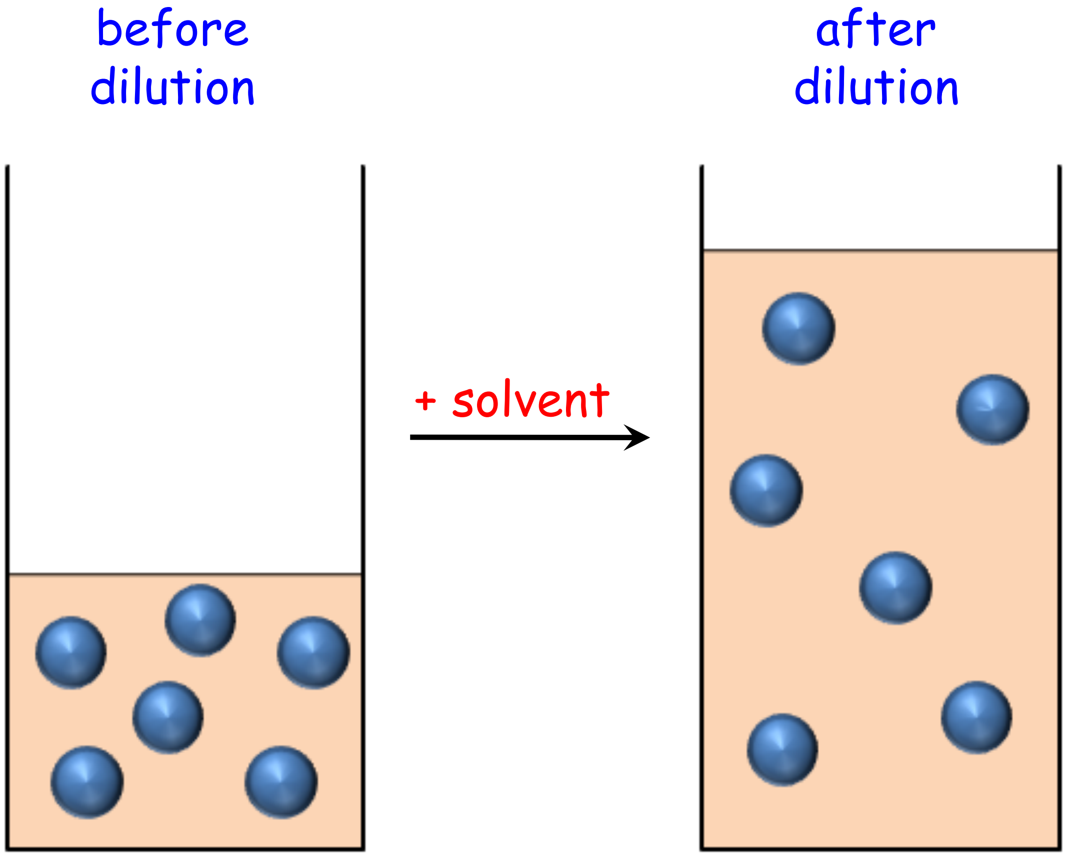
5 mL of the solution is aspirated with a 5 mL pipette

and transferred to a 500 mL volumetric flask

the volume is brought to 500 mL with water. The new solution is 0.001 M

The $V_{final}/V_{initial}$ ratio is called dilution (in this case 500/5=100)

The fundamental point in dilutions is that the number of moles of solute in the diluted solution is the same as in the intial more concentrated one.



$$c_{\text{initial}} = \frac{n}{V_{\text{initial}}}$$

$$c_{\text{final}} = \frac{n}{V_{\text{final}}}$$

Since the number of moles is constant we can write:

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

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

The concentration of the diluted solution is obtained as:

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

Example: How many mL of water should be added to 300 mL of a 0.25 M NaCl aqueous solution to bring the concentration to 0.1 M?

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

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

$$V_{\text{final}} = \frac{c_{\text{initial}}}{c_{\text{final}}} \cdot V_{\text{initial}} = \frac{0.25}{0.1} 300 = 750 \text{ mL}$$

since $V_{\text{final}} = V_{\text{initial}} + V_{\text{added}}$ it follows that $V_{\text{added}} = 400$ mL

Conversions between units of concentration

You need to know how to convert between different concentration units The units of concentration can be divided into:

- units involving mass ratios (%w, molality, mole fraction) useful in the study of colligative properties

- units involving mass-volume ratios (molarity, % w/V) peso/volume). useful in stoichiometry calculations.

The conversion between one type of mass/mass unit and the other is relatively simple.

To convert a mass/mass unit to a mass/volume unit it is necessary to convert the mass to volume, and vice versa, using density.