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SOLUBILITY AND CONCENTRATION UNITS

The solubility of a substance is the maximum amount of that substance that can be dissolved in a particular solvent at a particular temperature. When this maximum amount of solute has been added, the solution is said to be saturated. In this state, the solution is in a state of dynamic equilibrium: The two opposite processes of dissolution and precipitation (or crystallization) are taking place at the same rate.

If more solute is added to a saturated solution, it will not dissolve. For example, at 18°C, a maximum of 83 g of glucose ($C_6H_{12}O_6$) will dissolve in 100 mL of H_2O. Thus, we can say that the solubility of glucose is 83 g/100 mL. If more glucose is added, it will remain in solid form, precipitating to the bottom of the container. In some unique temperature conditions more solid can be dissolved than is allowed, in which case the solution is said to be supersaturated. This is, however, an unstable system, and often the slightest disturbance would cause the excess solute to precipitate out.

A solution in which the proportion of solute to solvent is small is said to be dilute, and one in which the proportion is large is said to be concentrated. Of course, very often we need to specify the amount of solute dissolved in a solvent more exactly, and this is expressed by the quantity of concentration. Solubility, then, can be thought of as the maximum possible concentration for the given solute-solvent pair in question. In the example above, we mentioned that the maximum concentration of glucose in water at 18°C is 83 g/100 mL. More commonly, however, the concentration of a solution is expressed as percent composition by mass, parts per million, mole fraction, molarity, molality, or normality.

Percent Composition by Mass

The percent composition by mass of a solution is the mass of the solute divided by the mass of the solution (solute plus solvent), multiplied by 100.

Example: What is the percent composition by mass of a salt water solution if 200 g of the solution contains 0.3 mol of NaCl?

Solution: First we need to convert the amount of NaCl into mass:

$$\begin{aligned} 0.3 \text{ mol NaCl} &= 0.3 \text{ mol} \times (\text{atomic mass of } Na^{+} + \text{atomic mass of } Cl^{-}) \\ &= 0.3 \text{ mol} \times (23 + 35.5) \text{ g/mol} \\ &= 17.6 \text{ g NaCl} \end{aligned}$$

$$\text{percent by mass} = (17.6 \text{ g}/200 \text{ g}) \times 100\% = 8.8\%$$

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Mole Fraction

The mole fraction (X) of a compound is equal to the number of moles of the compound divided by the total number of moles of all species within the system. The sum of the mole fractions in a system will always equal 1.

Example: If 92 g of glycerol is mixed with 90 g of water, what will be the mole fractions of the two components? (MW of H_2O = 18; MW of $C_3H_8O_3$ = 92)

Solution:

$$90 \text{ g water} = 90 \text{ g} \times (1 \text{ mol}/18 \text{ g}) = 5 \text{ mol}$$

$$92 \text{ g glycerol} = 92 \text{ g} \times (1 \text{ mol}/92 \text{ g}) = 1 \text{ mol}$$

$$\text{total number of moles} = 5 + 1 = 6$$

$$X_{\text{water}} = 5 \text{ mol}/6 \text{ mol} = 0.833$$

$$X_{\text{glycerol}} = 1 \text{ mol}/6 \text{ mol} = 0.167$$

Since these are the only two components in the system, one can verify that the two mole fractions add up to be 1.

Molarity

The molarity (M) of a solution is the number of moles of solute per liter of solution. Solution concentrations are usually expressed in terms of and in units of mol/L, also abbreviated M molarity. Molarity depends on the volume of the solution, not on the volume of solvent used to prepare the solution. In other words, mixing 1 mol of solute with 1 L of solvent will not in general give a 1 M solution since the final volume after mixing may be different from 1 L. You may recall from your laboratory experience that in order to produce a solution of a particular molarity, you add solvent to a container (volumetric flask) that already has the solute weighed out in it, until the total volume of the mixture reaches a specific value (marked by a ring around the narrow neck of the flask). One generally is not interested in, and does not keep track of, the volume of solvent actually added.

Example: If enough water is added to 11 g of $CaCl_2$ to make 100 mL of solution, what is the molarity of the solution?

Solution:

$$11 \text{ g } CaCl_2 = 0.10 \text{ mol } CaCl_2$$

$$100 \text{ mL} = 0.10 \text{ L}$$

$$\therefore \text{ molarity} = 0.10 \text{ mol}/0.10 \text{ L} = 1.0 \text{ M}$$

DON'T MIX THESE UP ON TEST DAY

Do not confuse molarity and molality!

Molarity = moles of solute/volume of solution

Molality = moles of solute/mass of solvent

Molality

The molality (m) of a solution is the number of moles of solute per kilogram of solvent. For dilute aqueous solutions at 25°C the molality is approximately equal to the molarity, because the density of water at this temperature is 1 kilogram per liter and the volume of the solution is presumed to be approximately the same as that of the solvent (i.e., water) added. But note that this is an approximation and true only for dilute aqueous solutions.

Example: If 10 g of NaOH are dissolved in 500 g of water, what is the molality of the solution?

Solution: 10 g NaOH = 0.25 mol NaOH

500 g = 0.5 kg

$\therefore$ molality = 0.25 mol solute/0.5 kg solvent = 0.50 m

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DILUTION

A solution is diluted when solvent is added to a solution of high concentration to produce a solution of lower concentration. The concentration of a solution after dilution can be conveniently determined using the equation below:

$$M_iV_i = M_fV_f$$

where M is molarity, V is volume, and the subscripts i and f refer to initial and final values, respectively. Note that the product MV gives the number of moles of solute, and the equation is just a statement on the conservation of matter: The amount of solute dissolved in the solution remains constant after a dilution.

Example: How many mL of water must be added to 65 mL of a 5.5 M solution of NaOH in order to prepare a 1.2 M NaOH solution?

Solution: The first step is to find the final volume of the solution:

$$5.5 \text{ M} \times 0.065 \text{ L} = 1.2 \text{ M} \times V_f$$

$$V_f = 5.5 \times 0.065/1.2 = 0.3 \text{ L} = 300 \text{ mL}$$

The volume of water that needs to be added is therefore

$$(300 - 65) \text{ mL} = 235 \text{ mL}$$