

Solutions and Concentrations

Solutions are **homogeneous mixtures**, meaning they are composed of at least two substances and are uniform throughout.

All solutions have two components:

1. Solute - the substance that is dissolved, usually present in the smaller amount
2. Solvent - the substance in which the solute is dissolved, usually the larger amount.

Concentration is a **quantitative** measure of the amount of solute dissolved in a given volume of solvent. (Quantitative = numbers)

We can also use a **qualitative** analysis of solutions (Qualitative = qualities/descriptions)

A solution is considered **concentrated** if there is a large amount of solute per unit volume. Usually > 1.0 mol/L.

A solution is considered **dilute** if there is a small amount of solute per unit volume. Usually < 1.0 mol/L.

There are a number of different ways to calculate concentration. One of the most common is MOLAR CONCENTRATION.

1. **Molar Concentration** is defined as the number of moles of solute dissolved to produce one litre of solution.

$$[\text{solution}] = n_{\text{solute}} / v$$

where [] = concentration = C

n = number of moles of solute

v = volume in L

$$C = \frac{n}{v}$$

The units are mol/L or mol · L⁻¹, moles per litre. IF YOUR VOLUME IS GIVEN IN MILLILITRES, mL or any thing else, YOU MUST CONVERT TO LITRES, L.

Example: Find the molar concentration of a solution in which 1.0 mol of ammonium sulfate is dissolved in water to form 5.00 x 10² mL of solution.

Answer: Given n = 1.0 mol
v = 5.00 x 10² mL = 0.500 L

Find C

$$C = \frac{n}{v} = \frac{1.0 \text{ mol}}{0.500 \text{ L}} = 2.0 \text{ mol/L}$$

REMEMBER YOUR SIGNIFICANT DIGITS
YOU MAY HAVE TO REARRANGE YOUR FORMULA TO SOLVE FOR OTHER VARIABLES.

Example #2 What volume of 6.00 mol/L hydrochloric acid solution contains 0.445 mol of hydrogen chloride?

Given : C = 6.00 mol/L
n = 0.445 mol
v = ?

Rearrange your formula, if $C = \frac{n}{v}$ then

$$v = \frac{n}{C} = \frac{0.445 \text{ mol}}{6.00 \text{ mol/L}} = 0.0742 \text{ L}$$

There are other types of concentration calculations besides molar concentration. Here are the ones we study in 2202, there are many others besides these!

1. Molar concentration (also called molarity)
 2. Molality
 3. Mole Fraction
 4. Percent Mass
 5. Percent Volume
 6. Percent Mass per Volume
2. Molality - the number of moles of solute dissolved in 1 kg of solvent

$$\text{molality} = \frac{\text{moles of solute}}{\text{mass of solvent (in kg)}}$$

$$\text{molal} = \frac{n_{\text{solute}}}{m_{\text{solvent}}}$$

*** To change from volume of water to mass of water use this conversion- 1 mL of water = 1 g of water

Example : Find the molality of a solution formed from 2.1 mol of sugar added to 926.7 mL of water.

Change your volume of water to kilograms. 926.7 mL =
926.7 g = 0.9267 kg

$$\begin{aligned}\text{Molality} &= \frac{2.1 \text{ mol}}{0.9267 \text{ kg}} \\ &= 2.3 \text{ mol/kg}\end{aligned}$$

3. Mole Fraction - this is the ratio of moles of solute compared to the total moles of both solute and solvent.

$$\text{Mole Fraction} = \frac{\text{moles of solute}}{\text{(moles of solute + moles solvent)}}$$

Example : Find the mole fraction of a solution formed when 15.4 moles of sugar is added to 124 moles of water.

$$\text{Mole fraction} = \frac{15.4 \text{ mol}}{(15.4 + 124)} = 0.11$$

Note there is no unit for mole fraction

4. Percent Mass - this is the mass of solute compared to the mass of the solution, then converted to a percentage.

$$\% \text{ mass} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

The units are % $\frac{\text{g}}{\text{g}}$

Example : 26.7 g of NaCl was added to water to make a 321 mL solution. Calculate the percent mass of the NaCl solution.

$$\begin{aligned} \% \text{ mass} &= \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\% \\ &= \frac{26.7 \text{ g}}{321 \text{ g}} \times 100\% = 8.32\% \text{ g/g} \end{aligned}$$

5. Percent by Volume - this is the volume (v) of a liquid solute per total volume (v) of solution, then translated to a percent

$$\% \text{ v/v} = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

The units are % mL/mL

Example : 25.0 mL of methanol is added to enough water to make a 126.00 mL solution. What is the percent volume?

$$\begin{aligned} \% \text{ v/v} &= \frac{\text{volume of solute}}{\text{volume of solution}} \times 100 \% \\ &= \frac{25.0 \text{ mL}}{126.00 \text{ mL}} \times 100 \% \\ &= 19.8\% \text{ mL/mL} \end{aligned}$$

6. Percent Mass per Volume - this is the mass of the solute per total volume of solution, then translated to a percent

$$\% \text{ m/mL} = \frac{m_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

The units are % g/mL

Example : Calculate the percent mass per volume for 87.5 g of NaCl dissolved in 250.0 mL.

$$\begin{aligned} \% \text{ m/ml} &= \frac{m \text{ (solute)}}{v \text{ (solution)}} \times 100 \% \\ &= \frac{87.5 \text{ g}}{250.0 \text{ mL}} \times 100\% = 35.0 \% \text{ g/mL} \end{aligned}$$

Now try these:

1. 15.0 g of gold in a 25.0 g copper and gold alloy - percent by mass
2. 15.00 mL of acetic acid mixed with enough water to make 300.0 mL of vinegar - percent by volume
3. 2.50 g of potassium chloride is dissolved in enough water to a 125 mL solution percent mass by volume
4. 0.750 mol of sodium nitrate is dissolved in 6.00 mol of water - mole fraction
5. 0.0200 mol of potassium chromate in 1.00 kg of water - molality

More Important Definitions Dealing with Solutions

Miscible - means a liquid that will dissolve in another liquid. Ethanol is miscible in water.

Immiscible - means a liquid that will not dissolve in another liquid. Oil is immiscible in water.

The amount of solute that can dissolve gives rise to these terms: saturated, unsaturated, and supersaturated.

Saturated - the maximum amount of solute is dissolved in a given solvent

Unsaturated - below the maximum amount of solute dissolved in a given solvent

Supersaturated - above the maximum amount of solute dissolved. This can be accomplished by heating the solution to dissolve extra solute.

How do we tell which category a solution falls in?

Add more solute

- if the addition of one crystal of solute causes all the crystals to reappear - it was super-saturated.

- if the addition of a few more crystals dissolve and therefore disappear - it was unsaturated.

- if the addition of few more crystals is visible, in other words does not disappear - it was saturated.

Saturated solutions are in a state of **DYNAMIC EQUILIBRIUM**

In a dynamic equilibrium of a saturated solution, the rate of dissolving (solute disappearing) is equal to the rate of re-crystallization (reappearing).

Solutions are either electrolytic (conducts electricity) or non - electrolytic (does not conduct electricity).

All ionic compounds that dissolve in water form **electrolytic** solutions. All acids are also electrolytic. Molecular compounds that dissolve in water are non-electrolytic.

Any ionic compounds that dissolves in water is said to **DISSOCIATE**. This means it separates into the ions that make it up. To determine whether it dissolves consult your solubility table.

Solution Preparation and the Dilution Formula

When we want to take a very concentrated solution and make it dilute we add more solvent, in our case, water.

Even if we add more water, we still have the same number of moles of solute in our diluted solution than we started with in our original concentrated solution.

Our original (initial) number of moles, n_i , is the same as our final number of moles, n_f .

$$n_i = n_f$$

We also know that $C = n/v$ and $n = Cv$, so $n_i = C_i v_i$ (original concentration times original volume) and $n_f = C_f v_f$ (final concentration times final volume)

since $n_i = n_f$, then we have a new formula:

$$C_i v_i = C_f v_f \quad \text{The dilution formula}$$

We can rearrange this formula to solve for any of the four variables. To help you identify which variables are given, use these simple rules: When two concentrations are given the larger value is C_i . If two volumes are given the larger value is v_f .

Example #1

Calculate the volume of 11.6 mol/L solution required to prepare 250.0 mL of 1.00 mol/L solution.

Given: $C_i = 11.6 \text{ mol/L}$

$C_f = 1.00 \text{ mol/L}$

$v_i = \text{unknown}$

$v_f = 250.0 \text{ mL} = 0.2500 \text{ L}$

$$\begin{aligned} C_i v_i &= C_f v_f & \text{So } v_i &= \frac{C_f v_f}{C_i} \\ & & &= \frac{11.6 \text{ mol/L} \times 0.2500 \text{ L}}{1.00 \text{ mol/L}} \\ & & &= 0.0216 \text{ L} \end{aligned}$$

Example #2 23.5 mL of an unknown concentration of acetic acid was added to enough water to make a volume of 3.25 L. If the final concentration of the solution is $6.5 \times 10^{-3} \text{ mol/L}$, what was the initial concentration?

$$C_i v_i = C_f v_f \quad \text{So } C_i = \frac{C_f v_f}{v_i}$$

Given:

$v_i = 23.5 \text{ mL} = 0.0235 \text{ L}$

$C_f = 6.5 \times 10^{-3} \text{ mol/L}$

$v_f = 3.25 \text{ L}$

$$\begin{aligned} C_i &= \frac{C_f v_f}{v_i} = \frac{(6.5 \times 10^{-3} \text{ mol/L})(3.25 \text{ L})}{0.0235 \text{ L}} \\ &= 0.90 \text{ mol/L} \end{aligned}$$