5.4: Concentration of solutions

The concentration of a solution tells the amount of solute dissolved in a given amount of solution.

Making a solution of know concentration

A measured amount of solute is dissolved in enough solvent to make the desired volume of the solution, as illustrated in Fig. 5.4.1. The concentration of the solution can be expressed in different ways using mass, volume, or mole units, as explained in the following.

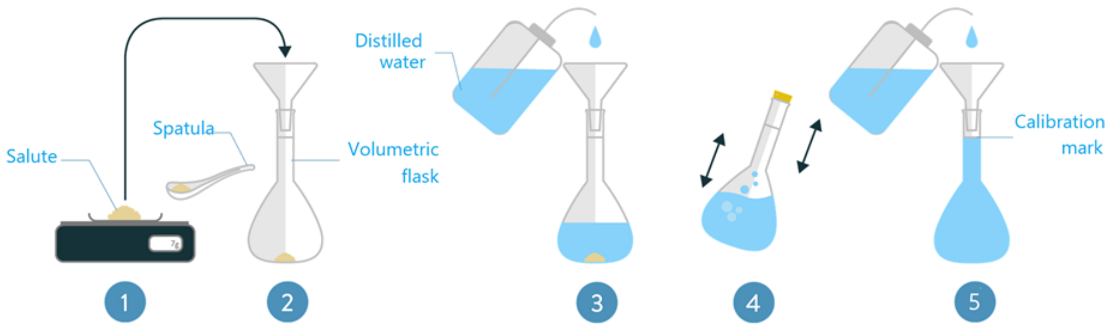

Figure 5.4.1: Making an aqueous solution: 1) measure the mass of the solute on an analytical balance, 2) pour the solute into a volumetric flask of know volume, 3) add distilled water (or solvent) to more than half fill the flask, 4) stopper the flask and shake it to dissolve the solute, 5) add more water to fill the flask to the calibration mark –measure from the lowest point of the water meniscus, 6) stopper the flask and shake again to make a homogeneous solution. Source: modified from https://www.hiclipart.com/free-trans...cvcrq/download

Concentration in percent (%)

What is percent (%)

Percentage (%) is a number or ratio that represent a fraction of 100.

For example, 5% means 5:100, where 5 is the part, and 100 is the total. The percentage is calculated as a hundred times of part by total, i.e.,

$$\text{Percentage } (\%) = \frac{\text{part}}{\text{Total}} \times 100.$$

Example 5.4.1

A 50.0 g NaCl is dissolved in water to make a 500 g solution. What is the percentage of NaCl in the solution?

Solution

Given part = 50.0 g NaCl, and total = 500 g solution. Desired: %NaCl in the solution?

Formula: $\text{Percentage } (\%) = \frac{\text{part}}{\text{Total}} \times 100.$

Calculations: $\text{Percentage } (\%) = \frac{50.0\mathit{cancel}\ \mathrm{g}}{500\mathit{cancel}\ \mathrm{g}} \times 100 = 10.0\ \%\mathrm{NaCl}$

The units cancel in the fraction calculation part, and a % sign is added to the answer to tell that it is a fraction out of a hundred.

Mass percent (m/m)% concentration

The mass percent concentration expresses the mass units of solute in a hundred mass units of the solution.

$$\text{Mass}(\%) = \frac{\text{mass of solute } (g)}{\text{mass of solute } (g) + \text{ mass of solvent } (g)} \times 100 = \frac{\text{mass of solute } (g)}{\text{mass of solution } (g)} \times 100$$

Note that the total is solute and solvent added together, i.e., solution.

Example 5.4.2

What is the mass % of NaOH in a solution prepared by dissolving 10.0 g NaOH in 100 g water?

Solution

Given solute = 10.0 g, and solvent = 100 g, Desired: Mass% NaOH?

Formula: $\text{Mass}\ (\%) = \frac{\text{mass of solute}\ (g)}{\text{mass of solute}\ (g) + \text{mass of solvent}\ (g)} \times 100$

Calculations: $\text{Mass}\ (\%) = \frac{10.0\ \text{gNaOH}}{(10.0\ \text{g}+100\ \text{g})\ \text{solution}} \times 100 = 9.09\%\text{NaOH}$

Note that the mass% concentration and its reciprocal are two conversion factor: $\frac{\text{given}\ g\,\text{solute}}{100g\,\text{solution}}$ and $\frac{100g\,\text{solution}}{\text{given g solute}}$

Example 5.4.3

Neosporin antibiotic is a 3.5% m/m neomycin solution. How many grams of neomycin are in 50 g of ointment?

Solution

Given: 3.5% neomycin $= \frac{3.5\ \text{g neomycin}}{100\ \text{g solution}}$, and Solution amount = 50 g, Desired: ? g neomycin

Calculations:

$$50\ \ \cancel{\text{g solution}} \times \frac{3.5\ \text{g neomycin}}{100\ \ \cancel{\text{g solution}}} = 1.8\ \text{g neomycin.}$$

Volume percent (v/v)% concentration

The volume percent concentration expresses the volume units of solute in a hundred volume units of the solution.

The mathematical form of the v/v % is:

$$\text{Volume}\ (\%) = \frac{\text{volume of solute (mL)}}{\text{volume of solution (mL)}} \times 100$$

Fig. 5.4.2 shows the volume percent concentration ranges of different classes of fragrances.

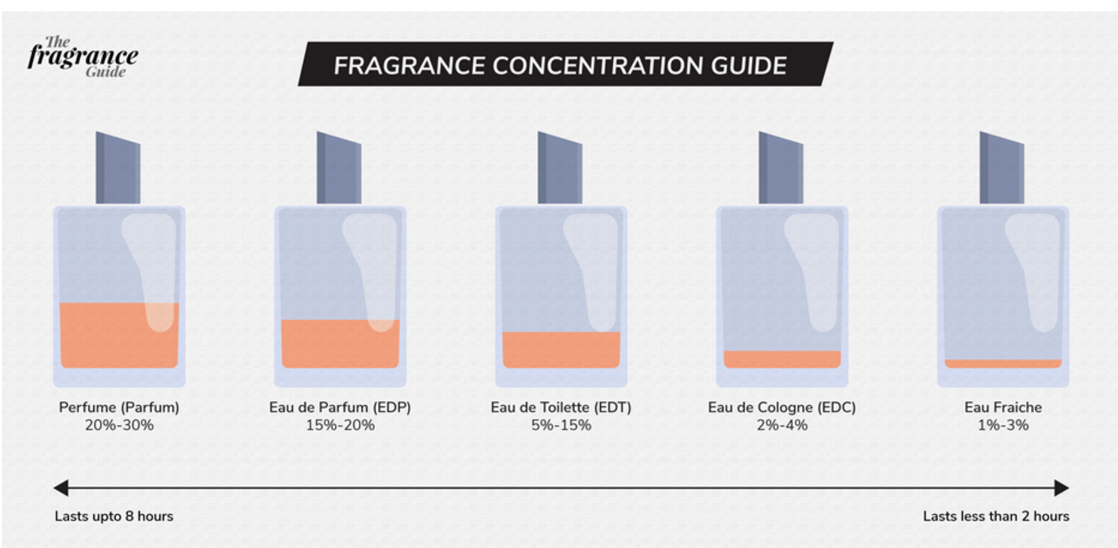

Figure 5.4.2: This info-graphic explains the differences between Parfums, Perfumes, Eau de Perfume, Eau de Parfum, Eau de Toilette, and Cologne. It also gives an approximate idea of how the concentration of Parfum oils vary as we move to lighter scents. Source: Nicole Smith / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)

Example 5.4.4

What is the volume % of rose extract in a solution prepared by dissolving 14.0 mL rose extract in a solvent to make 200 mL of solution?

Solution

Given: Solute = 14.0 g, and solution = 200 g, Desired: Volume% rose solution?

Formula:

$$\text{Volume }(\%)=\frac{\text{volume of solute }(mL)}{\text{volume of solution }(mL)}\times 100$$

Calculations:

$$\text{Volume }(\%)=\frac{14\text{ mL rose extract}}{200\text{ mL solution}}\times 100=7.0\%\text{ rose solution}$$

The two conversion factors for v/v % concentration are:

$$\frac{\text{given mL solute}}{100\text{ mL solution}}\text{ , and }\frac{100\text{ mL solution}}{\text{given mL solute}}$$

Example 5.4.5

What is the volume of bromine (Br_2) in 250 mL of 4.8% v/v of Br_2 solution in carbon tetrachloride?

Solution

Given: Concentration 4.8% v/v bromine $=\frac{4.8\ mL\text{ bromine}}{100\ mL\text{ solution}}$, volume of solution = 250 mL, Desired: Volume of solute, i.e., ? mL bromine.

Calculations:

$$250\text{ mL solution}\times\frac{4.8\text{ mL bromine}}{100\text{ mL solution.}}=12\text{ mL bromine.}$$

Mass/volume percent (m/v)% concentration

The mass/volume percent concentration expresses the mass units of solute in a hundred volume units of solution.

Mathematical form of m/v % is:

$$\text{Mass/volume }(\%)=\frac{\text{mass of solute }(g)}{\text{volume of solution }(mL)}\times 100$$

Example 5.4.6

What is the mass/volume % of glucose solution prepared by dissolving 50 g glucose in enough water to make 1000 mL of solution?

Solution

Given: Solute = 50.0 g, and Solution = 1000 mL, Desired: Mass/volume % glucose solution?

Formula:

$$\text{Mass/volume }(\%)=\frac{\text{mass of solute }(g)}{\text{volume of solution }(mL)}\times 100$$

Calculations:

$$\frac{\text{Mass}}{\text{volume}}(\%) = \frac{50 \text{ g glucose}}{1000 \text{ mL solution}} \times 100 = 5.0\% \text{ glucose solution by } \frac{\text{m}}{\text{v}}.$$

The two conversion factors from ms/v % concentration are:

$$\frac{\text{given } g \text{ solute}}{100 \text{ mL solution}} \quad \text{and} \quad \frac{100 \text{ mL solution}}{\text{given g solute}}$$

Example 5.4.7

How many grams of clindamycin antibiotics are in a 45 mL capsule of the 1.0% (m/v) clindamycin?

Solution

Given: % m/v concentration: 1.08 % m/v clindamycin $= \frac{1.0 \text{ g clindamycin}}{100 \text{ mL solution}}$, and volume of solution = 45 mL, Desired: ? g clindamycin?

Calculations:

$$45 \text{ mL solution} \times \frac{1.0 \text{ g clindamycin}}{100 \text{ mL solution}} = 4.5 \text{ g clindamycin.}$$

Parts per million (ppm) and parts per billion (ppb) concentration

Parts per million (ppm) is a number or ratio expressed as a fraction of a million (10^6).

For example, 2 ppm means $\frac{2}{1,000,000}$ or 2:1,000,000, where 2 is the part, and 1,000,000 is the total. The concentration in ppm is calculated as a million times of part by total, i.e.:

$$\text{Concentration in ppm } = \frac{part}{\text{Total}} \times 10^6$$

Parts per billion (ppb) is a number or ratio expressed as a fraction of billion (10^9).

That is:

$$\text{Concentration in ppb } = \frac{\text{part}}{\text{Total}} \times 10^9$$

Like percentage concentration, the ppm and ppb can be mass/mass (m/m), volume/volume (v/v) or mass/volume (m/v).

Example 5.4.8

EPA's action limit for copper is 1.3 mg/L in drinking water. What is this limit in ppm of copper m/v in the drinking water?

Solution

Given: 1.3 mg copper in 1L solution, Desired: ? ppm m/v of Copper in water

Formula: $\text{Concentration in ppm } = \frac{\text{solute(g)}}{\text{solution(mL)}} \times 10^6$

Calculations: First, convert the given units of mass and volume into the corresponding units that the formula takes, then plug the values in the formula and calculate.

$$\text{Solute } = 1.3 \text{ mg} \times \frac{1 \text{ g}}{1000 \text{ mg}} = 0.0013 \text{ g}$$

$$\text{Solution } = 1 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 1000 \text{ mL}$$

$$\text{Concentration in ppm } = \frac{0.0013 \text{ g}}{1000 \text{ mL}} \times 10^6 = 1.3 \text{ ppm copper } v/\text{m}$$

✔ Example 5.4.9

EPA's action limit for lead is 0.015 mg/L in drinking water. What is this limit in ppb of lead m/v in the drinking water?

Solution

Given: 0.015 mg in 1L solution, Desired: ? ppb m/v of Lead in water

Formula: $\text{Concentration in ppb } = \frac{\text{solute}(g)}{\text{solution}(\text{mL})} \times 10^9$

Calculations: First, convert the given units of mass and volume into the corresponding units that the formula takes, then plug the values in the formula and calculate.

$$\text{Solute } = 0.015\text{ mg} \times \frac{1\text{ g}}{1000\text{ mg}} = 0.000015\text{ g}$$

$$\text{Solution } = 1\text{ L} \times \frac{1000\text{ mL}}{1\text{ L}} = 1000\text{ mL}$$

$$\text{Concentration in ppb } = \frac{0.000015\text{ g}}{1000\text{ mL}} \times 10^9 = 15\text{ ppb lead v/m}$$

Molarity

Molarity (M) expresses the moles of solute in a liter of solution.

The most common solution concentration unit used in chemistry is molarity (M):

$$\text{Molarity } (M) = \frac{n \text{ (moles of solute)}}{V \text{ (Litters of solution)}}$$

✔ Example 5.4.10

What is the molarity (M) of a solution prepared by dissolving 50.0 g NaOH in enough water to make 250 mL solution?

Solution

Given: Solute = 50.0 g NaOH, Volume of solution = 250 mL, Desired: ? M NaOH solution?

Formula: $\text{Molarity } (M) = \frac{n \text{ (moles of solute)}}{V \text{ (Litters of solution)}}$

Calculations: First, convert the given units of mass and volume into the corresponding units that the formula takes, then plug the values in the formula and calculate.

$$\text{Solute } = 50.0\text{ g NaOH} \times \frac{1\text{ mol NaOH}}{40.00\text{ g NaOH}} = 1.25\text{ mol NaOH}$$

$$\text{Solution } = 250\text{ mL} \times \frac{1\text{ L}}{1000\text{ mL}} = 0.250\text{ L}$$

$$\text{Molarity } (M) = \frac{1.25\text{ mol NaOH}}{0.250\text{ L solution}} = 5.00\text{ M NaOH}$$

The two conversion factor from molarity are the following:

$$\frac{n \text{ (moles of solute)}}{V \text{ (Litters of solution)}} \quad \text{and} \quad \frac{V \text{ (Litters of solution)}}{n \text{ (moles of solute)}}$$

✔ Example 5.4.11

How many litters of 0.211 M HCl solution are needed to provide 0.400 mol of HCl?

Solution

Given: amount of solute = 0.400 mol HCl, Concentration of solute = 0.211M = $\frac{0.211 \text{ mol HCl}}{1 L \text{ solution}}$

Calculations:

$$\text{Liters of solution needed } = 0.400 \text{ mol HCl} \times \frac{1 \text{ L soluton}}{0.211 \text{ mol HCl}} = 1.90 \text{ L solution}$$

Example 5.4.12

A 2.50 L of 1.12 M NaOH solution contains how many moles of NaOH?

Solution

Given: Volume of solution = 2.50 L solution, concentration of solution = $1.12 \text{ M NaOH} = \frac{1.12 \text{ mol NaOH}}{1 \text{ L solution}}$, Desired: ? moles of NaOH?

Calculations:

$$\text{Moles of NaOH in the solution } = 2.50 \text{ L solution } \times \frac{1.12 \text{ mol NaOH}}{1 \text{ L solution}} = 2.80 \text{ mol NaOH}$$

Dilution of solutions

Dilution of a solution is the addition of a solvent to decrease the solute concentration of the solute in the solution.

The product of concentration (C) and volume (V) is the amount of solute, i.e.,

$$\text{Amount of solute } = C \text{ in } \frac{\text{amount of solute}}{\text{volume of solution}} \times V \text{ in volume of solution.}$$

The amount of solute does not change by adding solvent. Therefore, the product of concentration and volume, i.e., CV, which is the amount of solute, is a constant, i.e.,

$$C_1V_1 = C_2V_2 = \text{ amount of solute}$$

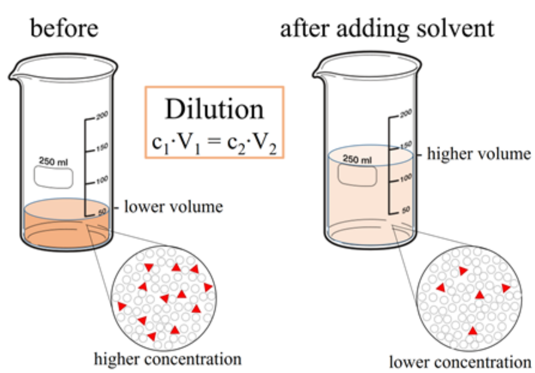

Figure 5.4.3: This image illustrates that when more solvent is mixed with the solution, the amount of solute remains the same, but its concentration decreases. Source: Theislikerice / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)

Fig. 5.4.3 shows that if the initial concentration is C_1, the initial volume is V_1, and after dilution, the final concentration is C_2, the final volume is V_2, then $C_1V_1 = C_2V_2$ = amount of solute that is constant. If three of the four variables in this equation are known, the missing one can be calculated, as explained in the following example.

Caution

Keep in mind that the concentrations and volumes should be in the same units on both sides of the equation: $C_1V_1 = C_2V_2$. If they are not in the same units, convert them to the same units before plunging them in the formula.

Example 5.4.13

how much volume of 11.3 M HCl is needed to prepare 250 mL of 2.00 M HCl?

Solution

Given: C_1 = 11.3 M HCl, C_2 = 2.00 M HCl, V_2 = 250 mL solution, Desired V_1 = ?

Formula: $C_1V_1 = C_2V_2$, rearrange it to isolate the desired parameter: $V_1 = \frac{C_2V_2}{C_1}$

Calculations:

$$V_1 = \frac{C_2V_2}{C_1} = \frac{2.00 \text{ M HCl} \times 250 \text{ mL solution}}{11.3 \text{ M HCl}} = 44.2 \text{ mL solution}$$

Example 5.4.14

what is the molarity of the NaOH solution prepared by diluting 100 mL of 0.521 M NaOH solution to 500 mL?

Solution

Given C_1 = 0.521 M NaOH, V_1 = 100 mL solution, V_2 = 500 mL solution, Desired: Concentration of the final solution C_2 = ? M NaOH

Formula: $C_1V_1 = C_2V_2$, rearrange to isolate the desired parameter: $C_2 = \frac{C_1V_1}{V_2}$

Calculations:

$$C_2 = \frac{C_1V_1}{V_2} = \frac{0.521 \text{ M NaOH} \times 100 \text{ mL NaOH}}{500 \text{ mL NaOH}} = 0.104 \text{ M NaOH}$$

Example 5.4.15

Dopamine is administered intravenously to a patient to increase blood pressure. How many milliliters (mL) of a 4.0% (m/v) dopamine solution is needed to prepare 250 mL of a 0.030% m/v) solution?

Solution

Given: C_1 = 4.0% (m/v), C_2 = 0.030% (m/v), V_2 = 250 mL solution, Desired V_1= ?

Formula: $C_1V_1 = C_2V_2$, rearrange to isolate the desired parameter: $V_1 = \frac{C_2V_2}{C_1}$

Calculations:

$$V_1 = \frac{C_2V_2}{C_1} = \frac{0.030\% \times 250 \text{ mL solution}}{4.0\%} = 5.0 \text{ mL of solution}$$

Logarithmic dilution

Take a unit volume of a given solution and add enough solvent to increase the volume of the solution 10 times for a logarithmic diluiton.

A logarithmic dilution is ten times dilution, i.e., proven by the following formula:

$$C_2 = \frac{C_1V_1}{V_2} = \frac{1 \text{ mL} \times C_1}{10 \text{ mL}} = 0.1 \times C_1$$

Repeating the above step with the diluted solution results in 10x10 = 100-time dilution, and repeating third-time results in 10x10x10 = 1000-time dilution. This dilution of 10 times in each step is called logarithmic dilution. Fig. 5.4.4 shows that five steps of logarithmic dilution on a 10% initial solution results in a concentration of 10 ppm in the final solution.

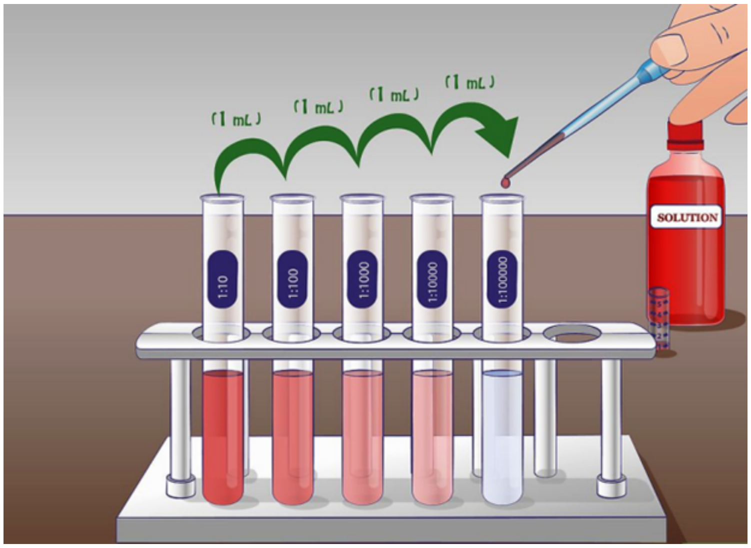

Figure 5.4.4: Logarithmic dilution: five steps of logarithmic dilution on a 10% initial solution results in a concentration of 10 ppm of the final solution. Source: Grasso Luigi / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)