Calculating Solution Concentration

Health, Safety & Environment

Many of the reagents used in research are in the form of solutions that are either purchased or prepared. Calculating the concentration of your prepared solution is an essential skill for both laboratory experiments and proper waste disposal. This document outlines how to prepare solutions and move between different concentration units.

Basic concepts covered:

- preparing solutions using **molarity**
- preparing solutions using **percent**
- converting between **molarity** & **percent**
- examples of percent composition of **chemical wastes**

Health, Safety & Environment only accepts chemical waste requests submitted in **percent** concentration.

PREPARING SOLUTIONS USING MOLARITY

Molarity is the most common unit of solution concentration and is defined as the number of moles per one *litre* of solution. To prepare a solution of given molarity, or to calculate the molarity, the following are needed:

- Molar mass of the solute (**MM**) - grams in one mole of solute
- Volume of the solution (**V**) - in litres
- Molarity (**M**) of the solution
- Equation (**1**): grams of solute (**g_s**) required = MM X M X V
- Equation (**2**): used to calculate concentrations or volumes: $M_1V_1 = M_2V_2$

Example starting with a solid chemical

Calculate the grams of potassium chloride (KCl) required to make 750 mL of 2M solution.

Step 1: Find the molar mass of KCl:

$$74.55\ \frac{grams}{mol}$$

Step 2: Using Equation (**1**), calculate the grams of solute (KCl) needed by cancelling out the units.

$$g_s = 74.55\ \frac{grams}{\cancel{mol}} \times 2\ \frac{\cancel{mol}}{\cancel{litre}} \times 0.75\ \cancel{litres}$$

$$g_s = 111.83\ grams$$

Step 3: Dissolve 111.83 grams of KCl into roughly 400 mL of distilled water, then add more water until the final volume is 750 mL

Example starting with a solution of liquid reagent

Prepare 500 mL of 1 M sodium hydroxide (NaOH) from concentrated (12 M) NaOH stock solution

Step 1: Assign known values to the variables in Equation (**2**). Litres or millilitres can be used for V, as long as the **same** unit is used for both V_1 and V_2.

M_1 = Molarity of stock solution = 12 M
V_1 = Volume of stock solution = *x* mL
M_2 = Molarity of prepared solution = 1 M
V_2 = Volume of prepared solution = 500 mL

Step 2: Determine the volume of stock solution needed to make 0.5 L of 1M NaOH by solving for *x*

$$M_1V_1 = M_2V_2$$

$$(12\ M)(x) = (1\ M)(500\ mL)$$

$$x = \frac{(1\ \cancel{M})(500\ mL)}{12\ \cancel{M}}$$

$$x = 41.67\ mL$$

Step 3: Added approximately 41.67 mL of concentrated 12 M NaOH to about 200 mL of distilled water, stir, then dilute up to 500 mL (by adding 258.33 mL of water)

PERCENT SOLUTIONS

Calculating percent solution

Many reagents are mixed as percent solutions, typically either as weight per volume (**w/v**) when using dry reagents, or volume/volume (**v/v**) when using liquid reagents. Occasionally, percent solutions are mixed using weight per weight (**w/w**). In each case, percent refers to **parts per hundred.** The percent will be different depending on which percent unit you decide to use, w/v, v/v, or w/w

Mass-volume percent solutions are defined as the grams of solute per 100 mL of solution

Example: 1 g of bromothymol blue in 100 mL of water is a 1% w/v solution.

Volume percent solutions are defined as millilitres of solute per 100 mL of solution

Example: 10 mL of ethanol plus 90 mL of water is approximately a 10% v/v solution. Note, this would change, if the 10 mL of ethanol was a 70% v/v ethanol solution in water:

1. First find how many mL of the 10 mL are ethanol (ie. What is 70% of 10 mL)

   $$10 \times 0.7 = 7\,mL$$

   Thus, of the 10 mL ethanol solution:

   7 mL ethanol
   3 mL water

   The total solution is therefore:

   7 mL ethanol
   93 (90+3) mL water

The final concentration is 7% v/v ethanol and 93% water (see 'A note on volumes').

Mass percent solutions are defined as the grams of solute per 100 grams of solution

Example: 20 g of sodium chloride in 100 g of solution is a 20% w/v solution.

Converting between percent solutions

You may want to convert between mass percent to volume percent, or vice versa. This is how you do so:

A 15% w/w sodium chloride (NaCl) solutions in water contains 15 g of sodium chloride and 85 g of water. What is the v/v %?

Step 1: Equation (**3**) is the formula for determining the volume of a solute:

$$volume = \frac{mass\ of\ solute\ (g)}{density\ of\ solute\ (\frac{g}{mL})}$$

$$volume = \frac{15\ g}{2.16\ \frac{g}{mL}}$$

$$volume = 6.94\ mL$$

Step 2: Find the density of a 15% (by weight) sodium chloride solution by searching the literature (see 'A note on density')

$$1.1\ g/mL$$

Step 3: Determine the volume of the total solution (Equation (**3**)) by dividing the mass of the solution (100 g, given) by the density of the solution (1.1 g/mL, found)

$$volume = \frac{100\ g}{1.1\ \frac{g}{mL}} = 90.90\ mL$$

Step 4: Determine the percent by volume by dividing the volume of the solute by the volume of the solution.

$$percent = \frac{volume\ of\ solute\ mL}{volume\ of\ solution\ mL} = \frac{6.94\ mL}{90.90\ mL}$$

$$percent\ = 0.08\ \times 100\% = 8\%$$

A 15% w/w NaCl solution is the 'same' as an 8% v/v NaCl solution.

Reverse the procedure to convert volume percent to mass percent.

A note on volumes

Percent volume is not always calculated from the sum of the volumes of the mixed components. This is because as components are mixed together, they may interact to form more 'tight' or 'loose' spaces between the molecules, resulting in a volume that is not the exact sum of the volumes mixed together. Ethanol is an example of this, where if you add 10 mL ethanol to 90 mL water, you will get slightly less than 100 mL of water.

PERCENT TO MOLARITY

Calculating molarity from percent solutions

You may want to convert your percent solution to molarity (or vice versa). To do so, will depend on what type of percent solution you are starting with: w/v, v/v, or w/w.

From w/v to molarity

What is the molarity of at 37.2% w/v hydrochloric acid (HCl) solution? (37.2 grams / 100 mL)

Step 1: Find the MM of HCl

$$MM = 36.45\ g/mol$$

Step 2: Divide the w/v% by the MM. Convert mL to L.

$$\frac{37.2\ \cancel{grams}}{100\ \cancel{mL}} \times \frac{mole}{36.45\ \cancel{grams}} \times \frac{1000\ \cancel{mL}}{1\ L}$$
$$= 10.2\ \frac{mol}{L}(M)$$

The molarity of a 37.2% w/v HCl solution is 10.2 M.

From v/v to molarity

What is the molarity of a 37.2% v/v HCl solution? (37.2 mL / 100 mL)

Step 1: Find the density and MM of HCl:

$$density = 1.48\ g/mL$$
$$MM = 36.45\ g/mol$$

Step 2: Using Equation (**3**) calculate the mass of hydrochloric acid in the solution (recall that a 10% v/v solution is 10 mL of solute in 100 mL of solution):

$$mass = density\ \times volume$$
$$mass = 1.48 \frac{g}{\cancel{mL}} \times 10\ \cancel{mL}$$
$$mass = 14.8\ grams$$

Step 3: Determine the w/v % of solution:

$$\frac{14.8\ grams}{100\ mL}$$

Step 3: Follow Step 2 in '**From w/v to molarity**'

$$\frac{14.8\ \cancel{grams}}{100\ \cancel{mL}} \times \frac{mole}{36.45\ \cancel{grams}} \times \frac{1000\ \cancel{mL}}{1\ L}$$
$$= 4.1 \frac{mol}{L}(M)$$

The molarity of a 37.2% v/v HCl solution is 4.1 M.

From w/w to molarity

What is the molarity of a 37.2% w/w HCl solution? (37.2 grams / 100 grams)

Step 1: Find the density of the *solution* by doing a literature search:

$$1.19\ g/mL$$

Step 2: Find the MM of HCl

$$36.45\ g/mol$$

Step 3: Covert percent mass of solute into decimal form

$$37.2\% = \frac{37.2\ grams}{100\ grams} = 0.37$$

Step 4: Multiply the decimal percent by the density and divide by the MM to find mol/mL. Convert to mol/L to determine molarity

$$Molarity = \ 0.37\ \times \frac{1.19\ \cancel{g}}{\cancel{mL}} \times \frac{mol}{36.45\ \cancel{g}}\ X\ \frac{1000\ \cancel{mL}}{1\ L}$$
$$Molarity = 12.1\ M$$

The molarity of a 37.2% w/w HCl solution is 12.1 M.

A note on solution density

When working with dilute solutions (consisting mostly of water) it usually okay to assume that solution density is 1 g/mL. However, when working with more concentrated solutions, the density of the solution must be considered as it will often be greater than 1 g/mL, thereby greatly affecting concentration calculations.

*It is important to note that the density of the **solution** is **different** than the density of the **solute**. Density of many solutions can be found by searching online, or referring to the SDS Section 9. (In addition, when purchasing solutions, the SDS typically offers percentages in Section 2).*

Calculating percent composition of complex chemical solutions

In order to submit and receive pick-up of hazardous chemical wastes, your waste must be in: (1) percent, totaling 100% (in descending order); (2) full English (no abbreviations); (3) packaged and tagged correctly.

1. *You are preparing a 10X TE buffer stock solution by adding 100 mL of 1 M Tris-chloride and 20 mL 0.5 M of EDTA, and adding distilled water to a final volume of 1 L. What is the percent composition of this solution?*

Step 1: Find the MM of each solute

Tris-hydrochloride = 157.59 g/mol

EDTA = 292.24 g/mol

Step 2: Calculate the mass of each solute added by using Equation (**1**):

Tris-hydrochloride

$$grams = \frac{1\ \cancel{mol}}{\cancel{L}} \times \frac{157.59\ g}{\cancel{mol}} \times 0.1\ \cancel{L}$$
$$grams = 15.78$$

EDTA

$$grams = \frac{0.5\ \cancel{mol}}{\cancel{L}} \times \frac{292.24\ g}{\cancel{mol}} \times 0.02\ \cancel{L}$$
$$grams = 2.9$$

Step 3: Calculate the w/v%:

$$\frac{weight\ of\ solute\ (g)}{volume\ of\ solution\ (mL)} \times 100\%$$

Tris-hydrochloride

$$\frac{15.78\ (g)}{1000\ (mL)} \times 100\% = 1.6\ \%$$

EDTA

$$\frac{2.9\ (g)}{1000\ (mL)} \times 100\% = 0.3\%$$

Step 4: Calculate the remaining % of solvent (water):

$$100\% - 1.6\% - 0.3\% = 98.1\%$$

Step 5: Record the percent composition:

98.1 % water, 1.6% Tris-hydrochloride, 0.3% ethylenediaminetetraacetic acid (w/v)

2. *You have a waste container that has 250 mL of 70% v/v ethanol, 20 mL of 95% w/w sulfuric acid and 680 mL of 100% w/w hexane. What is the percent composition of this solution? (Final volume is 950 mL)*

Step 1: Choose which percent composition unit you want the final percent to be in. In this case, w/w is a good choice because two of the components are already w/w.

Step 2: Convert 70% v/v (70 mL/100mL) ethanol to w/w. First find the mass of ethanol using its density (0.789 g/mL), then find the mass of the ethanol solution using the solution density (~0.88 g/mL), then use Equation (**3**)

$$weight\ of\ ethanol = 70\ \cancel{mL} \times 0.789 \frac{g}{\cancel{mL}} = 55.23\ g$$

$$weight\ of\ solution = 100\ \cancel{mL} \times 0.88 \frac{g}{\cancel{mL}} = 88\ g$$

Calculate the w/w percent:

$$w/w\% = \frac{weight\ of\ solute}{weight\ of\ solvent} \times 100\%$$

$$w/w\% = \frac{55.23\ g}{88\ g} \times 100\% = 62.76\%$$

Step 2: Determine the percent each solution contributes to the **final** volume (volume of solution / total volume)

$$ethanol\ solution = \frac{250\ mL}{950\ mL} \times 100\% = 26\%$$

$$sulfuric\ acid\ solution = \frac{20\ mL}{950\ mL} \times 100\% = 3\%$$

$$hexane\ solution = \frac{680\ mL}{950\ mL} \times 100\% = 71\%$$

Step 3: Calculate the **final** percent of each component by multiplying the w/w% by the decimal percent of the solution's contribution (determined in Step 2)

Ethanol: $62.76\%\ ethanol\ \times 0.26 = 16.3\%$

Sulfuric acid: $95\%\ sulfuric\ acid\ \times 0.03 = 2.9\%$

Hexane: $100\%\ hexane\ \times 0.71 = 71\%$

Step 4: Calculate the remaining % of solvent (water):

$$100\% - 16.3\% - 2.9\% - 71\% = 9.8\%$$

Step 5: Record the final percent composition:

71% hexane, 16.3% ethanol, 9.8% water, 2.9% sulfuric acid (w/w)

RESOURCES

1. https://www.snc.edu/chemicalhygiene/docs/labsafety/SolutionPrep.pdf
2. https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_(Petrucci_et_al.)/13%3A_Solutions_and_their_Physical_Properties/13.02%3A_Solution_Concentration