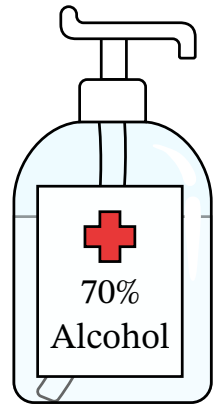
Explainer: Percentage Concentration

In this explainer, we will learn how to express and calculate the percentage concentration of a solution by its volume or mass ratio.

Have you ever noticed on the label of a tube of ointment, a medicine bottle, or a hand-sanitizer that the ingredients are followed by the notation %, % (v/v), or % (m/m)? The ingredients in bleach are also listed this way.



This notation describes the *percentage concentration* of the ingredients and is often used for solutions. You may be familiar with the term concentration. Concentration is a measure of the amount of solute dissolved in a given amount of solution.

Definition: Concentration

Concentration is a measure of how much solute is dissolved in a given amount of solution.

We can express concentration using the general equation

$$\text{concentration of a solution} = \frac{\text{amount of solute}}{\text{amount of solution}}.$$

The concentration of a solution can be described qualitatively. When there is a large amount of dissolved solute relative to the amount of solvent, we say the solution is concentrated, and when there is a small amount of dissolved solute relative to the amount of solvent, we say the solution is dilute.

We can also measure the concentration of a solution quantitatively using different units. The amount of solute and solution can be expressed in grams, millilitres, litres, cubic decimetres, or moles:

$$\text{concentration of a solution} = \frac{\text{amount of solute } (\text{g}, \text{mL}, \text{ or moles})}{\text{amount of solution } \left(\text{g}, \text{mL}, \text{L}, \text{ or } \text{dm}^3\right)}.$$

Percentage concentration is more specific. It is a measure of the amount of solute in every 100 units of solution.

Definition: Percentage Concentration

Percentage concentration is a measure of the amount of solute dissolved in every 100 units of solution.

The general equation for percentage concentration is

$$\text{percentage concentration of a solution} = \frac{\text{amount of solute } (\text{g}, \text{mL}, \text{ or L})}{\text{amount of solution } \left(\text{g}, \text{mL}, \text{L}, \text{ or } \text{dm}^3\right)} \times 100\%.$$

We can consider two types of percentage concentration, namely, mass percentage concentrationand volume percentage concentration.

When the amount of solute and the amount of solution are both expressed in grams, we can use mass-by-mass (m/m) concentration, which is also known as mass-per-mass concentration. The mass of the solution is equal to the sum of the mass of the solute and the mass of the solvent.

Take care to not use the mass of a solvent for the mass of the solution!

For example, if the mass of the solute in 50 g of solution is 2.5 g, the mass-by-mass (m/m) concentration is

$$\begin{aligned}\text{m/m concentration} &= \frac{\text{mass of solute } (\text{g})}{\text{mass of solute } (\text{g}) + \text{mass of solvent } (\text{g})} \\ &= \frac{\text{mass of solute } (\text{g})}{\text{mass of solution } (\text{g})}.\end{aligned}$$

Substituting in our values for the masses gives us

$$\begin{aligned}&= \frac{2.5\ \text{g}}{50\ \text{g}} \\ &= 0.05\ \text{g/g}.\end{aligned}$$

This means that there is 0.05 g of solute in every 1 gram of solution.

It is often more convenient to express a m/m concentration as a percent. We can convert the answer to a percent by multiplying a m/m value by 100%. Taking the same example,

$$\begin{aligned}\text{mass percent concentration } (\%\text{ m/m}) &= \frac{\text{mass of solute (g)}}{\text{mass of solution (g)}} \times 100\% \\ &= \frac{2.5\text{ g}}{50\text{ g}} \times 100\% \\ &= 5\text{ g/g}\% \\ &= 5\%.\end{aligned}$$

We can cancel the gram units to get a final answer of 5%. This value tells us that in every 100 g of solution there is 5 g of solute.

Example 1: Calculating the Percent by Mass Concentration

A sugar solution was made by mixing 12 g of glucose with 100 g of water. What is the percentage concentration by mass of the glucose in the solution? Give your answer to one decimal place.

A. 12.0% (m/m)

B. 8.3% (m/m)

C. 13.6% (m/m)

D. 10.7% (m/m)

E. 11.4% (m/m)

Answer

This question asks us to calculate the concentration of a glucose–water solution in terms of mass percent.

To calculate the mass percent of a solution, we require two mass values: the mass of the solute and the mass of the solution. In this example, we are given the mass of the solute (12 g of glucose), but we are not given the mass of the solution. However, as we are given the mass of the solvent in the question (100 g of water), we can calculate the mass of the solution.

To calculate the mass percentage concentration, we can use the following equation:

$$\text{mass percentage concentration } (\%\text{m/m}) = \frac{\text{mass of solute (g)}}{\text{mass of solute (g)} + \text{mass of solvent (g)}} \times 100\%.$$

We can substitute in the values for mass of solute and mass of solvent:

$$\text{mass percentage concentration} = \frac{12\text{ g}}{12\text{ g} + 100\text{ g}} \times 100\%$$

$$= \frac{12\ \text{g}}{112\ \text{g}} \times 100\%$$
$$= 10.714\ldots\ \%.$$

Remember that we can cancel the two gram units with each other. Also, remember to express the answer to one decimal place. The final answer is 10.7%.

When two or more solutions of different mass percentage concentrations are mixed, we can calculate the concentration of the new combined solution.

For example, if 13 g of a NaCl solution (of concentration 19% m/m) was added to 20 g of another NaCl solution (of concentration 22% m/m), we can determine the overall concentration of the new solution.

To calculate the total new mass percentage concentration, we will use the formula

$$\text{mass percentage concentration } (\%\text{m/m}) = \frac{\text{mass of solute } (\text{g})}{\text{mass of solution } (\text{g})} \times 100\%.$$

We can easily calculate the new total solution mass by adding the masses of both solutions:

$$\begin{aligned}\text{total solution mass} &= \text{mass of solution 1} + \text{mass of solution 2}\\ &= 13\ \text{g} + 20\ \text{g}\\ &= 33\ \text{g}.\end{aligned}$$

We do not know the total mass of solute. We can calculate the total mass of solute by first calculating the mass of solute in each solution and then summing these values together. So, to do this, we start by calculating the mass of solute in solution 1:

$$\%\ \text{m/m} = \frac{\text{mass of solute 1}}{\text{mass of solution 1}} \times 100\%$$

We can now substitute in our values,

$$19\% = \frac{\text{mass of solute 1}}{13\ \text{g}} \times 100\%,$$

and then rearrange the equation to solve for the mass of solute in solution 1:

$$\text{mass of solute 1} = \frac{19\% \times 13\ \text{g}}{100\%}$$
$$\text{mass of solute 1} = 2.47\ \text{g}.$$

Next, we calculate the mass of solute in solution 2:

$$\%\text{m/m} = \frac{\text{mass of solute 2}}{\text{mass of solution 2}} \times 100\%.$$

Now we can substitute in our values,

$$22\% = \frac{\text{mass of solute 2}}{20\text{ g}} \times 100\%,$$

and then rearrange the equation to solve for the mass of solute in solution 2:

$$\text{mass of solute 2} = \frac{22\% \times 20\text{ g}}{100\%}$$
$$\text{mass of solute 2} = 4.40\text{ g}.$$

Then, we can add the mass of solute 1 and the mass of solute 2 to get the total mass of solute:

$$\begin{aligned}\text{total solute mass} &= \text{mass of solute 1} + \text{mass of solute 2}\\ &= 2.47\text{ g} + 4.40\text{ g}\\ &= 6.87\text{ g}.\end{aligned}$$

Now we can calculate the new combined solution's concentration:

$$\begin{aligned}\text{mass percentage concentration (\% m/m)} &= \frac{\text{mass of solute (g)}}{\text{mass of solution (g)}} \times 100\%\\ &= \frac{6.87\text{ g}}{33\text{ g}} \times 100\%\\ &= 20.818\%\\ &\approx 20.8\%\text{ (to one decimal place)}.\end{aligned}$$

Example 2: Calculating the New Percent by Mass When Two Different Percent Solutions Are Mixed Together

50 g of a 26% (m/m) solution was mixed together with 130 g of a 17% (m/m) solution. What is the percentage concentration by mass of the new solution?

A. 19.5% (m/m)

B. 15% (m/m)

C. 5% (m/m)

D. 43% (m/m)

E. 35% (m/m)

Answer

To solve this problem, we need to know the total mass of solute and total mass of solution. We can start by calculating the total solution mass by adding the two solution masses together like this:

$$\begin{aligned}\text{total solution mass} &= \text{mass of solution 1} + \text{mass of solution 2}\\ &= 50\text{ g} + 130\text{ g}\\ &= 180\text{ g}.\end{aligned}$$

Calculating the total mass of solute involves a bit more work. First, we need to determine the mass of solute in each solution.

In solution 1, the mass of solute can be calculated by substituting the data we have for solution 1 into the mass percent equation:

$$\begin{aligned}\%\text{ m/m} &= \frac{\text{mass of solute 1}}{\text{mass of solution 1}} \times 100\%\\ 26\% &= \frac{\text{mass of solute 1}}{50\text{ g}} \times 100\%.\end{aligned}$$

We can then rearrange the equation to solve for mass of solute:

$$\begin{aligned}\text{mass of solute 1} &= \frac{26\% \times 50\text{ g}}{100\%}\\ \text{mass of solute 1} &= 13\text{ g}.\end{aligned}$$

We can do the same for solution 2, using the data we have for it:

$$\begin{aligned}\%\text{ m/m} &= \frac{\text{mass of solute 2}}{\text{mass of solution 2}} \times 100\%\\ 17\% &= \frac{\text{mass of solute 2}}{130\text{ g}} \times 100\%.\end{aligned}$$

We can then rearrange the equation and solve for mass of solute in solution 2:

$$\begin{aligned}\text{mass of solute 2} &= \frac{17\% \times 130\text{ g}}{100\%}\\ \text{mass of solute 2} &= 22.1\text{ g}.\end{aligned}$$

Then, we can add the mass of solute 1 and the mass of solute 2 to get the total mass of solute:

$$\begin{aligned}\text{total solute mass} &= \text{mass of solute 1} + \text{mass of solute 2}\\ &= 13\text{ g} + 22.1\text{ g}\end{aligned}$$

$$= 35.1 \text{ g}.$$

Now we can calculate the new combined solution concentration:

$$\begin{aligned}\text{mass percentage concentration } (\%\text{ m/m}) &= \frac{\text{mass of solute } (\text{g})}{\text{mass of solution } (\text{g})} \times 100\% \\ &= \frac{35.1 \text{ g}}{180 \text{ g}} \times 100\% \\ &= 19.5\%.\end{aligned}$$

Another way to express the concentration of a solution is in terms of volume of solute (for a liquid solute) and volume of solution. We call this a volume-by-volume (v/v) or volume-per-volume concentration. The volume values are usually expressed in the same unit, such as mL/mL or L/L. Usually mL/mL is used.

For example, if 24 mL of ethanol (C_2H_5OH) was added to water and the final solution's volume was 120 mL, we can calculate the volume-by-volume (v/v) concentration like this:

$$\text{v/v concentration} = \frac{\text{volume of solute } (\text{mL})}{\text{volume of solution } (\text{mL})}.$$

We can substitute the 24 mL of ethanol for the volume of solute and 120 mL for the volume of solution:

$$\begin{aligned}\text{v/v concentration} &= \frac{24 \text{ mL}}{120 \text{ mL}} \\ &= 0.2 \text{ mL/mL}.\end{aligned}$$

This value means that in every 1 mL of solution there is 0.2 mL of ethanol.

In this example, we were not told the volume of the solvent, water, but we were told about the volume of the solution. Sometimes a solute can influence the volume of a solvent due to particle interactions. Typically, we can make a solution by taking a known volume of solute and diluting it to a final, desired solution volume.

We can also express the volume-by-volume concentration in terms of a percent using this equation:

$$\text{volume percentage concentration } (\%\text{ v/v}) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%.$$

Using the same example we just used, we can determine the volume percentage concentration:

$$\begin{aligned}\%\text{ v/v} &= \frac{24 \text{ mL}}{120 \text{ mL}} \times 100\% \\ &= 20\%.\end{aligned}$$

This value tells us that, in every 100 mL of solution, there is 20 mL of ethanol.

Example 3: Calculating the Volume of Solute from a Percentage v/v Concentration

A 0.75 L bottle of vinegar contains 4% (v/v) of ethanoic acid. What volume of ethanoic acid does the bottle of vinegar contain?

Answer

The question asks us to calculate the volume of ethanoic acid in a 0.75 L vinegar solution of concentration 4% (v/v). We need to identify that ethanoic acid is the solute. To determine the volume of solute, we need to use the percentage concentration (v/v) equation:

$$\text{volume percentage concentration } (\%\text{ v/v}) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%.$$

We are told the volume percentage concentration (4%) and we are told the volume of the solution (0.75 L). We can substitute these values into the equation:

$$4\% = \frac{\text{volume of solute}}{0.75\text{ L}} \times 100\%.$$

Now we can rearrange the equation to solve for the volume of solute:

$$\begin{aligned}\text{volume of solute} &= \frac{4\% \times 0.75\text{ L}}{100\%} \\ &= 0.03\text{ L}.\end{aligned}$$

Note that if we had first converted the solution volume to millilitres, the final answer would also be in millilitres.

Example 4: Calculating the Volume of Water Added to Dilute a Solution to a Desired Concentration

What volume of water must be added to a 125 mL solution of ethanol to change its percentage volume from 40% (v/v) to 35% (v/v)? Give your answer to the nearest whole number.

A. 18 mL

B. 143 mL

C. 50 mL

D. 44 mL

E. 107 mL

Answer

We are told that we have a solution with a volume of 125 mL and a concentration of 40% (v/v). This solution is then diluted, by adding water, to a new concentration of 35% (v/v). We need to calculate how much water must be added to the initial volume to decrease the concentration from 40% (v/v) to 35% (v/v).

So, both the volume and the concentration of the initial solution and the diluted solution are different. However, the volume of the solute ethanol in both solutions is the same; it does not change.

We can begin by calculating how much ethanol is in the initial solution, and this will also be the amount of ethanol in the diluted solution. To calculate this we use the equation

$$\text{volume percentage concentration } (\%\text{ v/v}) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%.$$

Then, we can substitute in the volume and the concentration of the initial solution,

$$40\% = \frac{\text{volume of solute}}{125\text{ mL}} \times 100\%,$$

and solve for the volume of the solute ethanol in the initial solution:

$$\begin{aligned}\text{volume of solute} &= \frac{40\% \times 125\text{ mL}}{100\%} \\ &= 50\text{ mL}.\end{aligned}$$

This value of 50 mL is also the volume of ethanol in the dilute solution. So, we can calculate the volume of the dilute solution by substituting the volume of ethanol (50 mL) and the concentration of the dilute solution (35%) into the volume percentage equation:

$$\begin{aligned}\text{volume percentage concentration } (\%\text{ v/v}) &= \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\% \\ 35\% &= \frac{50\text{ mL}}{\text{volume of solution}} \times 100\%.\end{aligned}$$

Then, we can solve for the volume of the dilute solution:

$$\begin{aligned}\text{volume of solution} &= \frac{50\text{ mL} \times 100\%}{35\%} \\ &= 142.86\text{ mL}.\end{aligned}$$

Finally, we can subtract the volume of the initial solution from the volume of the dilute solution to determine how much water was added to the initial solution during dilution:

$$\text{volume of water added} = \text{volume of dilute solution} - \text{volume of initial solution}.$$

We can substitute in the volume of the initial and dilute solutions and subtract:

$$= 142.86 \text{ mL} - 125 \text{ mL}$$

$$= 17.86 \text{ mL}$$

$$\approx 18 \text{ mL}.$$

We must remember to round off the answer to the nearest whole number. So, 18 mL of water must be added to the initial solution to dilute it to the new desired concentration of 35% (v/v).

A third way to express the concentration of a solution is a mass-by-volume percentage (% m/v). This is the mass of solute (usually in grams) in a given volume of solution (usually 100 mL).

Definition: Mass-by-Volume Percentage concentration (%m/v)

It is a concentration unit for the mass of solute (in grams) in 100 volume units (usually millilitres) of solution.

The equation is

$$\text{mass-by-volume percentage concentration } (\% \text{ m/v}) = \frac{\text{mass of solute (g)}}{\text{volume of solution (mL)}} \times 100\%.$$

The units g and mL do not cancel with each other. Despite this, mass-by-volume percentage is commonly used in medicines. You may have noticed this unit written on ointment tubes or cough syrup bottles too.

Example 5: Calculating the Mass-by-Volume Percentage Concentration of a Solution

A saline solution was prepared by dissolving 9 g of NaCl in water to produce a solution with a total volume of 1 000 mL. What is the mass/volume percentage concentration, %(m/v), of the saline solution?

Answer

We can use the following equation for the mass/volume percentage concentration:

$$\text{mass-by-volume percentage concentration } (\% \text{ m/v}) = \frac{\text{mass of solute (g)}}{\text{volume of solution (mL)}} \times 100\%.$$

To solve this problem, we need to know the mass of the solute, which is 9 g of NaCl. And we need to know the volume of the solution, which is 1 000 mL. We can substitute these values into the equation:

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

$$= \frac{9\ \text{g}}{1\,000\ \text{mL}} \times 100\%$$
$$= 0.9\%.$$

Key Points

- The concentration of a solution is a measure of how much solute is dissolved in a given amount of solution.
- Percentage concentration is a measure of how much solute is dissolved in every 100 units of solution.
- Percentage concentration can be calculated in three ways, using the following equations:

$$\text{mass percentage concentration (\% m/m)} = \frac{\text{mass of solute (g)}}{\text{mass of solution (g)}} \times 100\%,$$
$$\text{volume percentage concentration (\% v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%,$$
$$\text{mass-by-volume percentage concentration (\% m/v)} = \frac{\text{mass of solute (g)}}{\text{volume of solution (mL)}} \times 100\%.$$