

14.5: Solution Concentration Measurements

Learning Objectives

- Express the amount of solute in a solution in various concentration units.

To define a solution precisely, we need to state its concentration: how much solute is dissolved in a certain amount of solvent. Words such as *dilute* or *concentrated* are used to describe solutions that have a little or a lot of dissolved solute, respectively, but these are relative terms with meanings that depend on various factors. **Concentration** is the measure of how much of a given substance is mixed with another substance. For example, vinegar is 5% acetic acid in water. A solution of 10% acetic acid would be more concentrated than a vinegar solution.

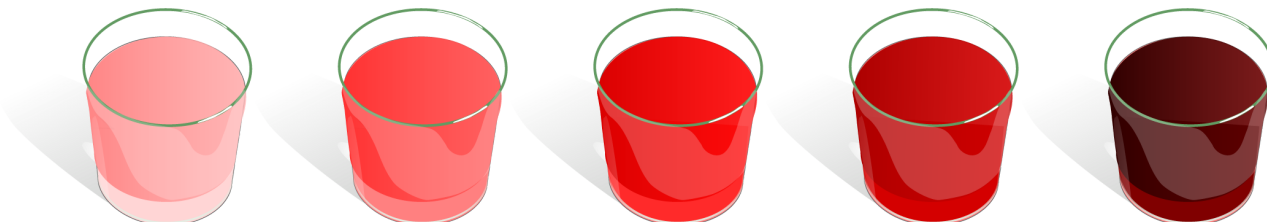


Figure 14.5.1 (left to right): Solutions of a red dye in water from the most dilute to the most concentrated. (adapted from gelokaliseer deur Naudefj via Wikimedia Commons).

Mass Percentage

There are several ways of expressing the concentration of a solution by using a percentage. The mass percentage, $\% \left(\frac{m}{m} \right)$, is defined as the mass of a solute divided by the mass of a solution times 100:

$$\% \left(\frac{m}{m} \right) = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\% \quad (14.5.1)$$

where

$$\text{mass of solution} = \text{mass of solute} + \text{mass of solvent} \quad (14.5.2)$$

As long as the masses of the solute and solution can be measured, determining the mass percentage is easy. It is important to remember that all masses must be expressed in the same units to properly calculate the concentration.

Example 14.5.1

Calculate the mass percentage of a solution prepared by dissolving 50.0 g $\text{C}_6\text{H}_{12}\text{O}_6$ in 200.0 g H_2O .

Solution

The mass of the solution (solute + solvent) = 50.0 g + 200.0 g = 250.0 g

These masses of the solvent and solution may then be substituted into [Equation 14.5.1](#):

$$\% \left(\frac{m}{m} \right) = \frac{50.0 \text{ g}}{250.0 \text{ g}} \times 100\% = \boxed{20.0\% \left(\frac{m}{m} \right) \text{ C}_6\text{H}_{12}\text{O}_6}$$

Exercise 14.5.1

A 2.00×10^2 g solution of Epsom salts (MgSO_4) contains 15.8 g of MgSO_4 . What is the mass percentage of the solution?

Answer

$$7.90\% \left(\frac{m}{m} \right) \text{ MgSO}_4$$

Using Mass Percentage in Calculations

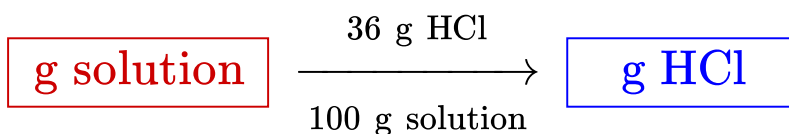
What if we wanted to prepare a specified amount of solution with a desired mass percentage? Using the mass percentage as a conversion is useful in this type of problem. The mass percentage may be expressed as a conversion factor in the form:

$$\frac{\text{g solute}}{100 \text{ g solution}} \text{ or } \frac{100 \text{ g solution}}{\text{g solute}}$$

For example, a solution that is 36% ($\frac{\text{m}}{\text{m}}$) HCl means that there are 36 g HCl for every 100 g of solution and may be expressed as a conversion factor as:

$$\frac{36 \text{ g HCl}}{100 \text{ g solution}} \text{ or } \frac{100 \text{ g solution}}{36 \text{ g HCl}}$$

Therefore, if we wanted to know the mass of HCl required to make 250 g of a solution that is 36% ($\frac{\text{m}}{\text{m}}$) HCl, a solution map may be generated, in a manner similar to when they were [first introduced](#) in this text:



✓ Example 14.5.2

Describe the preparation of 3000.0 g of 5.00% ($\frac{\text{m}}{\text{m}}$) NaCl.

Solution

Steps for Problem Solving

Identify the "given" information and what the problem is asking you to "find."

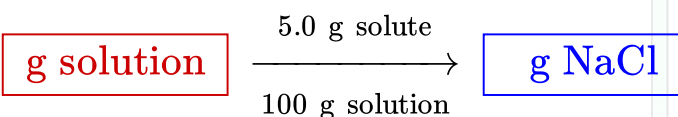
Given: 3000.0 g solution; 5.00% ($\frac{\text{m}}{\text{m}}$) NaCl

Find: mass of solute and solvent required, so solution prep can be described

List other known quantities.

$$\frac{5.0 \text{ g NaCl}}{100 \text{ g solution}}$$

Prepare concept map using the proper conversion factor(s).



Calculate the answer.

$$3000.0 \text{ g solution} \times \frac{5.00 \text{ g NaCl}}{100 \text{ g solution}} = \boxed{150 \text{ g NaCl}}$$

Mass solvent (H₂O) required = 3000.0 g solution – 150 g NaCl
solvent = 2850 g H₂O

Describe preparation.

Dissolve 150 g NaCl into 2850 g H₂O.

Steps for Problem Solving

Think about your result.

This makes sense, 150 g and 2850 g sum to 3000 g. In addition, 150 g is 5.00% of 3000.0 g.

Volume Percentage

Liquid volumes over a wide range of magnitudes are conveniently measured using common and relatively inexpensive laboratory equipment. The concentration of a solution formed by dissolving a liquid solute in a liquid solvent is therefore often expressed as a volume percentage, % ($\frac{v}{v}$):

$$\% \left(\frac{v}{v} \right) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\% \quad (14.5.3)$$

Just like the mass percentage, all volumes must be expressed in the same units to properly calculate the concentration. One important thing to note with a volume percentage is that volumes are not always additive, due to particle size and intermolecular forces. How could this be? Consider an example where 200 mL of sand were mixed with 200 mL of marbles. The combined volume would be less than 400 mL because the sand would fill the spaces between the marbles. How much less? It would depend on the size of the marbles and sand particles. While we couldn't predict the final volume, we could state with confidence it is less than 400 mL. Therefore, in a volume percentage, only the volume of the solute and volume of the solution are important.

A common usage is in the measurement ethanol content in alcoholic beverages. A beer that contains 5.8% ABV (alcohol by volume) means that it contains 5.8% ($\frac{v}{v}$) ethanol. For liquor, proof is defined as twice the ABV. Therefore, a whiskey labeled as 80 proof, is also 40% ABV, or 40% ($\frac{v}{v}$) ethanol.

As with the mass percentage, a volume percentage may also be expressed as a conversion factor in the form:

$$\frac{\text{mL solute}}{100 \text{ mL solution}} \text{ or } \frac{100 \text{ mL solution}}{\text{mL solute}}$$



Exercise 14.5.2

What is the volume of isopropyl alcohol found in a 1-pint (473 mL) bottle of rubbing alcohol that is 70.0% ($\frac{v}{v}$) isopropyl alcohol?

Answer

331 mL isopropyl alcohol

Mass-Volume Concentrations

“Mixed” percentage units, derived from the mass of solute and the volume of solution, are popular for certain biochemical and medical applications. A mass-volume percentage is a ratio of a solute's mass to the solution's volume expressed as a percentage. In a **mass-volume percentage**, grams are used for solute mass and mL are used for the solution volume. For example, physiological saline solution, used to prepare intravenous fluids, has a concentration of 0.9% ($\frac{m}{v}$) NaCl, indicating that the composition is 0.9 g NaCl per 100 mL solution.

The concentration of glucose in blood (commonly referred to as “blood sugar”) is also typically expressed in terms of a **mass-volume ratio**. Though not expressed explicitly as a percentage, blood glucose concentration is usually given in milligrams of glucose per deciliter (mg/dL) (1 dL = 100 mL) of blood (Figure 14.5.2).

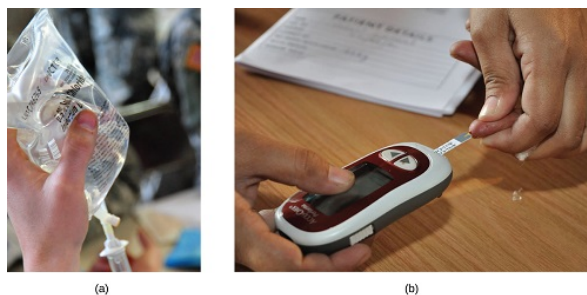


Figure 14.5.2: “Mixed” mass-volume units are commonly encountered in medical settings. (a) The NaCl concentration of physiological saline is 0.9% ($\frac{m}{v}$) NaCl. (b) This device measures glucose levels in a sample of blood. The normal range for glucose concentration in blood (fasting) is around 70–100 mg/dL. (credit a: modification of work by “The National Guard”/Flickr; credit b: modification of work by Biswarup Ganguly).

Parts per Million and Parts per Billion

Very low solute concentrations are often expressed using appropriately small units such as parts per million (ppm) or parts per billion (ppb). Like percentage (“part per hundred”) units, ppm and ppb may be defined in terms of masses, volumes, or mixed mass-volume units. There are also ppm and ppb units defined with respect to numbers of atoms and molecules.

The mass-based definitions of ppm and ppb are given here:

$$\text{ppm} = \frac{\text{mass solute}}{\text{mass solution}} \times 1,000,000 \quad (14.5.4)$$

$$\text{ppb} = \frac{\text{mass solute}}{\text{mass solution}} \times 1,000,000,000 \quad (14.5.5)$$

Both ppm and ppb are convenient units for reporting the concentrations of pollutants and other trace contaminants in water. Concentrations of these contaminants are typically very low in treated and natural waters, and their levels cannot exceed relatively low concentration thresholds without causing adverse effects on health and wildlife. For example, the EPA has identified the maximum safe level of fluoride ion in tap water to be 4 ppm. Inline water filters are designed to reduce the concentration of fluoride and several other trace-level contaminants in tap water (Figure 14.5.3).

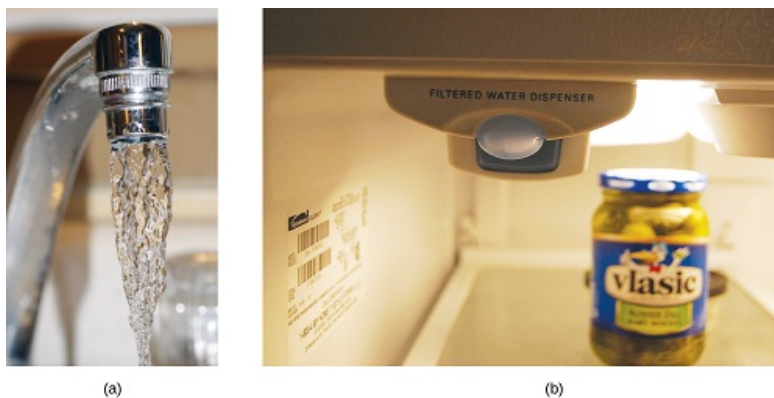


Figure 14.5.3: (a) In some areas, trace-level concentrations of contaminants can render unfiltered tap water unsafe for drinking and cooking. (b) Inline water filters reduce the concentration of solutes in tap water. (credit a: modification of work by Jenn Durfey; credit b: modification of work by “vastateparkstaff”/Wikimedia commons).

Exercise 14.5.3

Match the measurement with the quantity it is likely measuring:

- A. cholesterol levels in the blood
- B. fluoride content of toothpaste
- C. ethanol content of wine
- D. mercury content in drinking water

Choices:

- 180 mg/dL
- 0.8 ppb
- 0.15% ($\frac{m}{v}$)
- 12% ABV

Answer A

180 mg/dL is a typical measure of cholesterol levels in the blood.

Answer B

0.15% ($\frac{m}{v}$) represents the fluoride content of a typical toothpaste.

Answer C

12% ABV is the typical ethanol content of wine.

Answer D

0.8 ppb would likely be a typical mercury content in drinking water.

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