Concentration of solutions

A solution is a homogeneous mixture made up of two or more substances that can be solid, liquid or gaseous. In a solution, a substance, known as a solute, is mixed with another substance, known as a solvent.

When we mix two substances and we obtain a solution, we say that these substances are soluble. Solute is the substance that is in smaller proportion, unless it is water in which case we consider it the dissolvent.

When we mix two substances and we do not obtain a solution, we say that these substances are insoluble.

Solids may be dissolved in liquids (salt in water). Gases may be dissolved in liquids (carbon dioxide in water). Liquids may be dissolved in other liquids (alcohol in water). Gases can be combined with other gases to create mixtures (helium and oxygen) and solids can be combined with other solids to create alloys (stainless steel).

The concentration of a solution represents the relative amounts of solute and solvent in a solution.

A solution can be qualitatively described as dilute or concentrated.

- **Dilute**: a solution that contains a small proportion of solute relative to solvent.
- **Concentrated**: a solution that contains a large proportion of solute relative to solvent.

There are several ways to express solution concentration in Chemistry but we will see this year only three of them: percentage by mass, percentage by volume and gram per litre.
Examining the method of preparation of the three types may help you understand the differences among them. The following table compares these three ways of stating solution concentration.

<table>
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<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>How to prepare</th>
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</thead>
<tbody>
<tr>
<td>Percentage by mass</td>
<td>%</td>
<td>Grams solute per 100 g of solution</td>
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<tr>
<td></td>
<td></td>
<td>5 %: Dissolve 5 g of solute in 95 g of solvent</td>
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<tr>
<td>Percentage by volume</td>
<td>%</td>
<td>Litres (mililitres) of solute per 100 litres of solution</td>
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<tr>
<td></td>
<td></td>
<td>5 %: Dissolve 5 mL of solute in 95 mL of solvent</td>
</tr>
<tr>
<td>Gram per litre</td>
<td>g/L</td>
<td>Grams solute per litre of solution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 g/L: Dissolve 5 g of solute and add solvent to make 1 L of solution</td>
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</tbody>
</table>

You will find percentages of solutes stated on the labels of many commercial products, such as household cleaners, liquid pesticide solutions, and shampoos. If your sink becomes clogged, you might buy a bottle of drain opener whose label states that it is a 2.4% sodium hydroxide solution. This means that the bottle contains 2.4 g of NaOH for every 100 g of solution.

**How to solve percentage concentration by mass problems**

\[
\text{Mass of solute in grams} + \text{Mass of solvent in grams} = \text{Mass of solution in grams}
\]

\[
\% = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100
\]

% (percentage concentration)
Sample problem

What is the percentage by mass (% by mass) of a solution made by dissolving 0.49 g of potassium sulfate in 12.70 g of water?

ANALYSE

• What is given in the problem?
  The mass of solvent and the mass of solute, $K_2SO_4$

• What are you asked to find?
  The concentration of the solution expressed as a percentage by mass

Data:

Mass of solute: 0.49 g $K_2SO_4$
Mass of solvent: 12.70 g $H_2O$

• What step is needed to calculate the concentration of the solution as a percentage by mass?
  Divide the mass of solute by the mass of the solution and multiply by 100.

Solution

$$\% = \frac{0.49 \text{ g}}{12.70 \text{ g} + 0.49 \text{ g}} \times 100 = \frac{0.49 \text{ g}}{13.19 \text{ g}} \times 100 = 3.7 \%$$

This number means that in 100 g of solution there are 3.7 g of solute.
How to solve percentage concentration by volume problems

Sample problem

What is the percentage by volume (% by volume) of a solution made by dissolving 100 mL of ethanol in 15 mL of water?

ANALYSE

• What is given in the problem?
  The volume of solute and the volume of solvent. Be aware that in this case the water is considered the solvent although it is in a smaller proportion.

• What are you asked to find?
  The concentration of the solution expressed as a percentage by volume.

Data:

Volume of solute: 110 mL ethanol
Volume of solvent: 15 mL H₂O

- What step is needed to calculate the concentration of the solution as a percentage by mass?
  Divide the volume of solute by the volume of the solution and multiply by 100.

Solution

\[ \% = \frac{110 \text{ mL}}{15 \text{ mL} + 110 \text{ mL}} \times 100 = \frac{110 \text{ mL}}{125 \text{ mL}} \times 100 = 88 \% \]

This number means that in 100 mL of solution there are 88 mL of solute.

How to solve grams per litre concentration problems

\[ \text{Mass of solute in grams} + \text{Volume of solution in litres} = \text{Mass of solute per litre of solution} \]

\[ \frac{\text{Mass of solute (g)}}{\text{Volume of solution (L)}} = \text{g/L (gram per litre concentration)} \]

Gram per litre concentration
Sample problem

A solution is prepared by dissolving 36.4 g CaI$_2$ in enough water to have 750 mL of solution. What is the gram per litre concentration of the solution?

ANALYSE

- What is given in the problem?
  The mass of solute (CaI$_2$) and the volume of solution.

- What are you asked to find?
  The concentration of the solution expressed as gram per litre.

Data:

Mass of solute: 36.4 g CaI$_2$
Volume of solution: 750 mL H$_2$O + CaI$_2$

- What step is needed to calculate the concentration of the solution as gram per litre?
  Divide the mass of solute by the volume of the solution.

Solution

\[
g/L = \frac{36.4 \text{ g}}{0.750 \text{ L}} = 48.5 \text{ g/L}
\]

This number means that in 1 L of solution there are 48.5 g of solute.
Proposed problems

1. What is the percentage concentration of 75 g of ethanol dissolved in 500 g of water? \textit{answer:} 13.0 \% ethanol
2. A chemist dissolves 3.50 g of potassium iodate and 6.23 g of potassium hydroxide in 805.05 g of water. What is the percentage concentration of each solute in the solution? \textit{answer:} 0.430 \% KIO_3 and 0.765 \% KOH
3. A student wants to make a 5 \% solution of rubidium chloride using 0.377 g of the substance. What mass of water will be needed to make the solution? \textit{answer:} 7.16 g H_2O
4. What mass of lithium nitrate would have to be dissolved in 30 g of water in order to make an 18 \% solution? \textit{answer:} 6.59 g LiNO_3
5. A solution of sodium hydroxide, NaOH, contains 12 grams of solute in 4 litres of solution. What is the concentration of the solution in g/L? \textit{answer:} 3 g/L
6. A solution of sugar contains 35 grams of sucrose, C_{12}H_{22}O_{11} in 100 mL of solution. What is the concentration of the solution in g/L? \textit{answer:} 350 g/L
7. If the percent by volume is 2 \% and the volume of solution is 250mL what is the volume of solute in this solution? \textit{answer:} 5 mL
8. If I make a solution by adding water to 35 mL of methanol (CH_3OH) until the final volume of the solution is 275 mL, what is the percent by volume of methanol in this solution? \textit{answer:} 12.7 \%
9. What weight of solute is needed to produce each of the indicated solutions? How many grams of water should be used in each of the cases?
   \begin{itemize}
   \item \textit{a)} 500 g of a 6.40 \% NaCl solution. \textit{answer:} 32 g NaCl and 468 g H_2O
   \item \textit{b)} 136 g of a 14.2 \% LiNO_3 solution. \textit{answer:} 19.3 g LiNO_3 and 116.7 g H_2O
   \item \textit{c)} 42.2 g of a 7.60 \% AgNO_3 solution. \textit{answer:} 3.2 g AgNO_3 and 39 g H_2O
   \end{itemize}
10. What would be the percent concentration by mass of each of the following solutions? Remember that the density of water is 1 g/mL.

a) 54 g of AgNO$_3$ is dissolved in 128 g of water.
   \( \text{answer: } 29.67\% \)

b) 4.22 g of K$_2$CO$_3$ is dissolved in 426 mL of water.
   \( \text{answer: } 0.98\% \)

c) 0.762 g of ZnF$_2$ is dissolved in 1.30 litres of water.
   \( \text{answer: } 0.058\% \)