Concentration calculations

Calculating concentration of a chemical solution is a basic skill all students of chemistry must develop early in their studies. Concentration refers to the amount of *solute* that is dissolved in a *solvent*. We normally think of a solute as a solid that is added to a solvent, but the solute could just as easily exist in another phase. For example, if we add a small amount of ethanol to water, then the ethanol is the solute and the water is the solvent. If we add a smaller amount of water to a larger amount of ethanol, then the water could be the solute!

Once you have identified the solute and solvent in a solution, we can determine its concentration. Concentration may be expressed several different ways, using percent composition by mass, volume percent, mole fraction, molarity, molality, or normality.

Molarity (M) Molarity is probably the most commonly used unit of concentration. It is the number of moles of solute per liter of a solution (not necessarily the same as the volume of pure solvent!). The unit, used for this type of concentration is $\text{mol} \cdot \text{dm}^{-3}$.

Determine the molarity of a solution made when 11 g of $CaCl_2$ ($M_r = 110.98$) was dissolved in water and the volume of a final solution is 500 mL.

11 g of $CaCl_2$ is $\frac{11}{110.89} = 0.0992$ mol. This mass of substance is dissolved in 0.5 dm^{-3} of a final solution – it means, that the molarity is

$$c = \frac{0.0992}{0.5} = 0.1984 \text{ mol} \cdot \text{dm}^{-3}$$

Percent Composition by Mass (%) This is the mass of the solute divided by the mass of the solution (mass of solute plus mass of solvent), multiplied by 100.

To determine the percent composition by mass of a 20 g of a salt (m_{sa}), diluted in 100 g of a solvent (m_{sv}) we can use a simple calculation:

$$\frac{m_{sa}}{m_{sa} + m_{sv}} \cdot 100 = \frac{20}{20 + 100} \cdot 100 = 16.7 \ \%$$

The solubility is one of the important properties of chemical compounds. It is dependent on the solvent and also on the temperature. It is a concentration of a saturated solution of particular compound in a solvent at defined temperature.

In some tables, two ways for the solubility definition are used. The first is mass of a substance, which is dissolved in 100 g of a *solution*.

The second one is mass of a compound, which can be dissolved in 100 g of a *solvent* (in case of inorganic compounds usually water).

The water solubility of boric acid at 20 °C is 5.02 g/100 g of water. If we need the concentration in mass %, we can calculate it as mass of the boric acid (5.02 g) in 105.02 g of the solution (5.02 g of boric acid is dissolved in 100 g of water). The concentration of the solution is 4.78 %.

In case of a compound, where the solubility at 20 °C is defined as 5.02 g/100 g of solution the concentration is 5.02 %.

Molar concentrations

1. Calculate weight of potassium hydroxide ($M_r = 56.11$) needed for preparation of 250 mL of solution whith concentration of 0.3 $\mathrm{mol \cdot dm^{-3}}$. (4.21 g)

2. Calculate weight of cesium chloride ($M_r = 168.36$) needed for preparation of 2.5 L of solution whith concentration of 0.05 $\mathrm{mol \cdot dm^{-3}}$. (21.045 g)

3. Calculate molar concentration (in $\mathrm{mol \cdot dm^{-3}}$) of sodium hydroxide ($M_r = 40.0$), which was prepared by dissolving of 0.6 g of sodium hydroxide in water. The final volume of the solution is 400 mL. (0.0375 $\mathrm{mol \cdot dm^{-3}}$)

4. Calculate weight of potassium sulfate ($M_r = 174.26$), contained in 5.6 L of its solution with concentration of 0.25 $\mathrm{mol \cdot dm^{-3}}$ (243.96 g)

5. Calculate molar concentration (in $\mathrm{mol \cdot dm^{-3}}$) of copper sulfate ($M_r = 159.61$), which was prepared by dissolving of 22 g of *copper sulfate pentahydrate* ($M_r = 249.69$) in water. The final volume of the solution is 800 mL. (0.11 $\mathrm{mol \cdot dm^{-3}}$)

Mass concentrations, solubility

1. Calculate mass of water and sodium chloride needed for preparation of 500 g of the 0.9% solution. (4.5 g of NaCl and 495.5 g of water)

2. Calculate mass of water, needed for preparation of 3% solution from 8 g of boric acid. ... (258.67 g)

3. Calculate mass of water needed for dilution of 500 mL of 50% sulfuric acid to the 10% solution. Density of the 50% sulfuric acid is 1.395 $\mathrm{g \cdot cm^{-3}}$. (2790 g)

4. Calculate amount of water needed for preparation of 10% hydrochloric acid solution from 300 g of 30% hydrochloric acid. (600 g)

5. Calculate concentration (in mass percents) of solution, prepared by adding 300 g of water to 250 mL of 35% hydrochloric acid (ρ= 1.18 $\mathrm{g \cdot cm^{-3}}$). (17.35 %)

6. A solution of sulfuric acid was prepared from 20 mL of 96% sulfuric acid (ρ= 1.84 $\mathrm{g \cdot cm^{-3}}$) and 80 mL of water. Calculate concentration (in mass %) of the final solution. (30.25 %)

7. A solution of nitric acid was prepared from 200 mL of 65% nitric acid (ρ= 1.38 $\mathrm{g \cdot cm^{-3}}$) and 800 mL of water. Calculate concentration (in mass %) of the final solution. (16.67 %)

8. In 250 g of 10% solution of potassium sulfate was added 20 g of the solid sulfate. Calculate mass concentration of prepared solution. (16.67 %)

9. Calculate concentration of *sodium carbonate* ($M_r = 105.99$) in mass % of the solution prepared by dissolving of 200 g of *sodium carbonate decahydrate* ($M_r = 286.14$) in 550 g of water. (9.88 %)

10. Calculate mass of water, needed for preparation of saturated solution from 8 g of boric acid. Solubility of boric acid is 5.04 g/100 g of water. (158.73 g)

11. From 650 g of 15% solution of potassium bromide was evaporated 200 g of water. Calculate concentration in mass % of the prepared solution. (21.67 %)

12. There is potassium chloride solution $c = 2.0\ \mathrm{mol} \cdot \mathrm{dm}^{-3}$, its density is $\rho = 1.091\ \mathrm{g} \cdot \mathrm{cm}^{-3}$. Calculate its concentration in mass percents.
$M_r(\mathrm{KCl}) = 74.55$ (13,67 %)

13. Calculate molar concentration of the 20% solution of sulfuric acid.
$\rho = 1.14\ \mathrm{g} \cdot \mathrm{cm}^{-3}$; $M_r(\mathrm{H_2SO_4}) = 98.08$ ($2.32\ \mathrm{mol} \cdot \mathrm{dm}^{-3}$)

14. The sulfuric acid solution was prepared using 15 mL of its 24% solution ($\rho = 1.171\ \mathrm{g} \cdot \mathrm{cm}^{-3}$). It was diluted to final volume of 750 mL. Calculate molar concentration of the final solution in $\mathrm{mol} \cdot \mathrm{dm}^{-3}$. $M_r(\mathrm{H_2SO_4}) = 98.08$ ($0.0573\ \mathrm{mol} \cdot \mathrm{dm}^{-3}$)

15. Calculate volume of 35% HCl, which is needed for preparation of 2 litres of its solution $c = 4\ \mathrm{mol} \cdot \mathrm{dm}^{-3}$?
$M_r(\mathrm{HCl}) = 36.46$; density of 35% HCl $\rho = 1.18\ \mathrm{g} \cdot \mathrm{cm}^{-3}$ (706.25 ml)