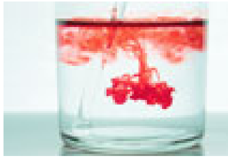


Solutions

Explore

Which factors impact the rate at which a solute dissolves?

Solubility

The solubility of a substance indicates how much of that substance will **dissolve** in a specified amount of **solvent** under certain conditions. Solubility is usually measured in terms of concentration at a given temperature and pressure.

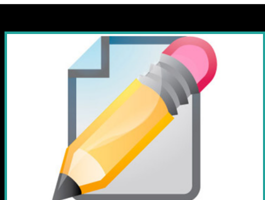
There are many factors that will increase or decrease solubility. As the surface area of a **solute** is increased, the rate of dissolving increases. Surface area is the amount of area a substance has on its exterior. For example, a teaspoon of sugar contains about the same mass of sugar found in a sugar cube. The teaspoon of loose sugar will dissolve faster, however, because it has more surface area available to interact with the solvent.

As the temperature of a solvent is increased, the rate of dissolving usually increases. This is because temperature is related to the kinetic energy of the particles involved. The more kinetic energy particles have, the more they react with one another. The more energy a solvent has, the more it can interact with a solute. Kinetic energy can also be added to the system by stirring or shaking it.

If the solute is a gas, however, temperature affects a **solution** in the opposite way. The increased kinetic energy of the solution allows the gas particles to move more freely, and they are more likely to escape from the solution.

Carbonated beverages exhibit another solubility rule, known as Henry's law. This law states that if temperature does not change, the amount of gas that dissolves in a liquid is proportional to the partial pressure of that gas in equilibrium with that liquid. For example, inside an unopened can of soda the pressure is much higher than that of the surrounding area. This pressure keeps carbon dioxide gas dissolved in the liquid soda solution. When the can is opened and pressure is decreased, though, the carbon dioxide escapes the solution.

The chemical makeup of the solvent and solute are also related to solubility. Remember that some molecules have a negative or positive charge because the electrons are not distributed evenly around them. These are referred to as polar molecules. Solutes of a specific **polarity** (negative or positive) will only dissolve in solvents with a similar polarity. The rule for this is "*like* dissolves *like*." For example, the oil and vinegar in salad dressing do not mix because vinegar is polar and oil is nonpolar. Water and vinegar, however, will form a solution because they are both polar.



Exploring the Relationship between Temperatu Solubility

Concentrations of Solutions

The concentration of a solution is a measure of how much solute is dissolved in a given amount of solvent. There are three ways the concentration of a solution can be described.

The first method for describing concentration is known as molarity. Molarity (*M*) gives the number of moles of solute divided by total number of liters of the solution.

$$M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Another way to describe solution concentration is the mole fraction. The mole fraction (X) of a solution is the ratio of moles of the solute to the total number of moles in a solution. Since mole fraction describes a percentage, it can never be greater than 1.

$$X = \frac{\text{moles of solute}}{\text{moles of solute and solvent combined}}$$

The final way to describe concentration is molality. Molality (*m)* is the number of moles of solute dissolved in one kilogram of the solvent.

$$m = \frac{\text{moles of solute}}{\text{1 kg of solvent}}$$

These methods of calculating concentration are most useful when solute concentrations are quite high.

Concentrations of Solutions: Sample Problem

A solution is formed by combining 0.250 moles of sodium chloride (NaCl) in 3.61 liters of water. Assume that the addition of NaCl does not significantly change the volume of the solution. The volume of the solution, then, is 3.61 L. Compare the molarity and the molality of NaCl in the solution. What is the mole fraction of NaCl in the solution? Assume that 1 liter of water has a mass of 1 kilogram.

Solution:

First, to calculate the molarity of the solution, substitute the given information into the molarity ratio:

$$M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

$$= \frac{0.250 \text{ mol}}{3.61 \text{ L}}$$

$$M = 0.0693 \text{ mol/L}$$

The molarity of the NaCl in the solution is 0.0693 mol/L. Notice that a volume of 3.61 L of solution is used in the calculation. The actual volume would be slightly higher due to the addition of NaCl. Notice also that the answer is expressed with the correct number of significant digits, which in this case is 3.

To find molality, substitute the given information into the molality ratio:

$$m = \frac{\text{moles of solute}}{\text{kg solvent}}$$

$$= \frac{0.250 \text{ mol}}{3.61 \text{ kg}}$$

$$m = 0.0693 \text{ mol/kg}$$

The molality of the NaCl in the solution is 0.0693 m.

Because water has a mass of 1 kg/L, the molarity and molality are about the same for this solution.

To find the mole fraction, several steps are needed. The ratio for mole fraction is

$$X = \frac{\text{moles of solute}}{\text{moles of solute and solvent combined}}$$

The value for the moles of solute NaCl is given as 0.250 mol. The total number of moles of solute and solvent combined must next be calculated.

The solution contains 3.61 kg of water, but the number moles of water must be determined. Because the molar masses of hydrogen and oxygen are given in grams, it is convenient to convert the mass of water in the solution to grams, as well.

$$3.16\ \cancel{\text{kg}} \times \frac{1000\text{ g}}{1\ \cancel{\text{kg}}} = 3160\text{ g}$$

The mass of the water in grams is 3,610 g. This value can be used to determine the moles of water in the solution.

From the periodic table, we can find the following atomic masses:

hydrogen (H) = 1.008 g

oxygen (O) = 16.0 g

These masses of two moles of hydrogen and one mole of oxygen are added together to find the molar mass of water.

(2 × 1.008 g/mol) + 16.0 g/mol = 18.016 g/mol

Next, we determine the number of moles in 3,160 g of water.

$$3160\ \cancel{\text{g}} \times \frac{1\text{ mol}}{18.016\ \cancel{\text{g}}} = 175.39964\text{ mol}$$

The total moles of the solute and solvent, then, equals

0.250 mol NaCl + 200.377 mol H_2O = 200.627 mol total

The mole fraction of NaCl in the solution is

$$X = \frac{\text{moles of solute}}{\text{moles of solute and solution}}$$

$$= \frac{0.250\text{ mol}}{175.64964\text{ mol}}$$

$$X = .0014253$$

Note that extra digits were used during this last set of calculations so that the moles of solute and total moles in the solution could be properly compared. The final answer, however, should again have 3 significant digits. The mole fraction of NaCl in the solution is about 0.125%.

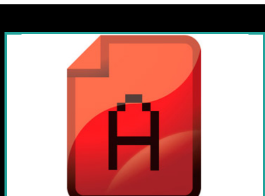
Using Molarity to Calculate the Dilutions of Solutions

A dilution is making a solution that has smaller amounts of solute than the original solution. In other words, it has a lower concentration than that of the original. This is usually done by adding more solvent to the solution to create a smaller ratio of solute to solvent.
To find a dilution of an existing solution of known concentration, the formula, Molarity1 x Volume1 = Molarity2 x Volume2, ($M_1V_1 = M_2V_2$), can be used.

Molarity1 is the known concentration of the initial solution and Volume1 is the known volume of the initial solution. Either the desired molar concentration must also be known or the new volume required. These would be Molarity2 and Volume2 values respectively. The fourth and final value can then be calculated.
An example of how this is done is as follows:
You have 5 liters of a 2 molar hydrochloric acid solution. What would the final concentration be if you added enough water to get a final volume of 20 liters?
M_1 = 2 M, V_1 = 5 liters, M_2 = unknown, and V_2 = 20 liters

Rearranging the formula to solve for the variable in question would be $M_2 = M_1V_1/V_2$. Substituting in the known values would give M_2 = 2M x 5L / 20 liters.

Solving the equation would give a value of 0.5M.



Check for Understanding: Molarity Calculations

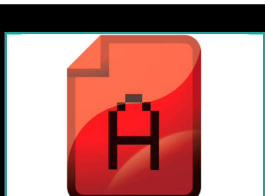
Saturated, Unsaturated, and Supersaturated Solutions

When a large amount of salt is mixed into cold water, some of it does not dissolve. In fact, the salt remains solid and settles on the bottom of the container.

Because of the way in which particles react, a solvent can dissolve only a certain amount of a solute. A saturated solution is a solution in which no more solute can be dissolved. In fact, if additional solute were added it could cause some dissolved solute to become solid and settle out of the solution. The solid that forms and separates from a solution is known as a precipitate.

An unsaturated solution is a solution that contains less solute than can be dissolved under existing conditions. If more solute is added, it will simply dissolve into the solvent.

Under special conditions, a saturated solution can be made to dissolve more solute. Most often, this requires the addition of heat or pressure to the system. For example, water at room temperature will dissolve a certain amount of sugar. When the solution becomes saturated, however, no additional sugar will dissolve. The solution becomes cloudy until the extra sugar settles to the bottom of the container. If the water is heated, more sugar can be dissolved into it. When the solution is allowed to cool back down, the extra sugar will remain dissolved. As a result, the final, cooler solution will contain more sugar than would normally dissolve in that volume of water at that temperature. This solution is supersaturated.



Check for Understanding: Saturated, Unsaturate Supersaturated Solutions

Electrolytes and Non-electrolytes

In a common science experiment, two electrodes are stuck in a lemon and attached to a conductivity meter. Amazingly, the lemon conducts electricity! Lemon juice contains citric acid, an **electrolyte**. An electrolyte is a substance that conducts electricity if it dissolves in water. Acids and bases are electrolytes, and so are most salts. A non-electrolyte is a substance that does not conduct when dissolved in water. Sugar and ethanol are non-electrolytes.

When an acid such as HCl dissolves in water, it produces ions. The same is true for a base such as NaOH. Similarly, when salts such as NaCl or KNO_3 dissolve in water, they produce ions.

$$HCl \rightarrow H^+ + Cl^-$$

$$NaOH \rightarrow Na^+ + OH^-$$

$$NaCl \rightarrow Na^+ + Cl^-$$

$$KNO_3 \rightarrow K^+ + NO_3^-$$

These ions are the reason why solutions of electrolytes can conduct electricity. Negative and positive ions move in the solution. They can carry electrical charge from one electrode to the other. Strong acids and bases are strong electrolytes, because they dissociate completely into ions. Weak acids and bases are weak electrolytes, because they dissociate only partly.

The conductivity of a solution is a measure of how well it conducts electricity. Conductivity depends on how many ions are present in the solution. For one electrolyte, a concentrated solution usually has a higher conductivity than a **dilute solution**.

Conductivity can be used to measure the concentration of a solution. Different electrolytes have different conductivities. The relationship between concentration and conductivity can be found for each electrolyte. (This data can be measured in the laboratory, or obtained from reference books.) Then this relationship can be used to identify an unknown concentration by measuring its conductivity.

Check for Understanding: Electrolytes and Non-electrolytes