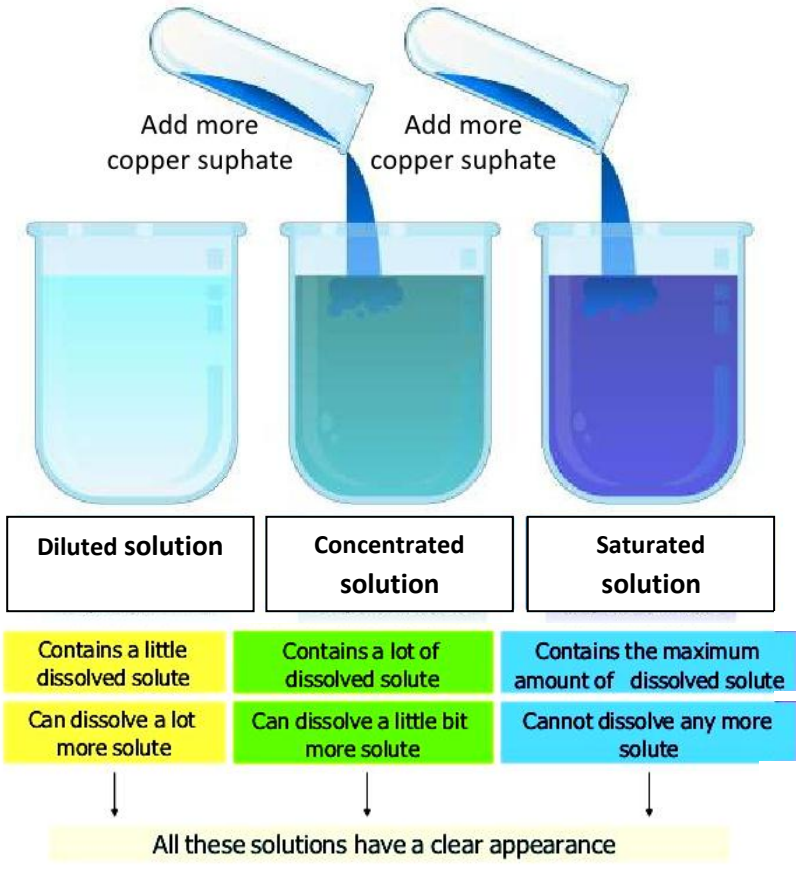
SCH 3U

SOLUTIONS & THEIR CONCENTRATIONS

Solutions are homogeneous mixtures. They consist of a solvent (a liquid, such as water) and one or more solutes (substances that are dissolved in the solvent.) The dissolving of a solute in a solvent is a physical change. However, chemical reactions often occur between substances that are in solution. These chemical changes can depend on the amount of substances — that is, their concentrations — in the solution.

You will often hear a solution referred to as dilute or concentrated. A dilute solution is one that contains a relatively small amount of the solute in a given volume of solvent. Tap water is an example of a dilute solution; it contains very small quantities of dissolved minerals.
A concentrated solution contains a relatively large amount of the solute in the same volume of solvent. Most commercial acids are concentrated solutions. For example, commercial hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) are concentrated solutions.

> Stomach acid is a dilute solution of hydrochloric acid. The acid aids in digesting the protein in foods. Anyone with an ulcer can attest to the problems that this dilute acid solution can cause!



TRY THIS!

Often when a solute is dissolved in a solvent, heat is either consumed or produced, as demonstrated by the following two activities.

1. Instant cold packs are used in first aid to treat injuries. They consist of a divided plastic bag containing a solid separated from blue-dyed water to allow you to see if the partition has broken. The solid is usually ***ammonium nitrate***. Cold packs work by using a physical process (not a chemical reaction) based on a solid dissolving in water. When the partition is broken, the solid and water mix. As the solid dissolves it absorbs energy from the surroundings, and you notice a cooling effect.

   Make an instant cold pack by placing 30 g (1/8 cup) of ammonium nitrate in a zipper-type plastic bag or plastic cup. Add 100 mL (1/2 cup) water at room temperature and stir the contents. Use a thermometer to measure the *drop* in temperature. The temperature will be lowered by about 15°C.

2. Mountain hikers and campers often carry hot packs during the winter months. Hot packs work in a manner similar to cold packs, except that the salt that dissolves in the water releases energy. That is, heat is evolved.

   Make an instant hot pack by placing 40 g (1/4 cup) calcium chloride in 100 mL (1/2 cup) of water at room temperature in a plastic bag or cup. Use a thermometer to measure the *rise* in temperature.

For many solutions, there is a limit to the amount of solute that can be dissolved in the solvent. A solution in which no more solute will dissolve is called a ***saturated solution***. When you add a lot of sugar to your ice tea, not all the sugar will dissolve, and your solution (of sugar in tea) is saturated. Under certain conditions, you can get an excess amount of solute to dissolve; that is, you can get more than the amount that is expected to dissolve in a saturated solution.
A solution that contains an excess of dissolved solute is called ***supersaturated***. Actually, a supersaturated solution is unstable and some solute will crystallize if the solution is disturbed. For example, adding a small crystal of the solute can start the crystallization. You may have noticed this phenomenon in a jar of honey. After the honey jar has been sitting for a long time, you might see solid sugar crystallizing.

The terms “dilute,” “concentrated,” and “saturated” can be useful when talking about how much solute is in a solution, but they do not tell us *exactly* how much solute is present. Chemists often need to express concentrations in more precise terms. There are many precise ways of expressing concentrations are described below.

① MASS PERCENT

Weight percent is often used to express the concentration of a solid substance dissolved in a liquid. The *weight percent* is equal to the weight of the substance (solute) divided by the total weight of the solution and multiplied by 100 to get a percentage.

$$\% \left(\frac{mass}{mass}\right) = \frac{mass\ of\ solute}{total\ mass\ of\ solution} \times 100\%$$

For example, a 1% sodium chloride solution in water contains 1 gram of sodium chloride (NaCl) in a total of 100 grams of solution. The amount of water is 99 grams, the difference between the total weight (100 grams) and the weight of the solute (1 gram).

② VOLUME PERCENT

Volume percent is often used to express the concentration of a liquid solute in a liquid solvent. The volume percent is equal to the volume of the solvent divided by the total volume of the solution and multiplied by 100 to get a percentage.

$$\% \left(\frac{volume}{volume}\right) = \frac{volume\ of\ solute}{total\ volume\ of\ solution} \times 100\%$$

Common rubbing alcohol is a 70% solution of rubbing alcohol (isopropyl alcohol) in water; that is, it contains 70 mL of isopropyl alcohol in 100 mL of total solution.

> The alcohol content of alcoholic beverages (vodka, gin, wines, whiskeys) is given in **proof**. The concentration of alcohol expressed in "proof" is double the volume percent. For example, a wine that is 12% alcohol by volume is 24 proof. Don't be fooled by this unit of proof. It does not mean you are getting more alcohol for your money!
>
> When preparing solutions, you might notice that the volume of the final solution is often less than the sum of the volumes of the original components; that is, the volumes are not additive!

③ MASS TO VOLUME PERCENT

$$\% \left(\frac{mass}{volume}\right) = \frac{mass\ of\ solute\ in\ g}{volume\ of\ solution\ in\ mL} \times 100\%$$

④ PARTS PER MILLION

Many environmental samples contain trace amounts of solute impurities and the concentration of these impurities are reported in *parts per million (ppm)*. Parts per million means the number of milligrams of substance dissolved in 1 liter of water. One ppm is the same as a penny in 1 million cents. The EPA recommended limit of lead in tap water is 0.015 ppm.

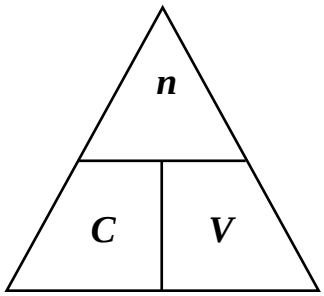
$$parts\ per\ million\ (ppm) = \frac{mass\ of\ solute}{mass\ of\ solution} \times 10^6$$

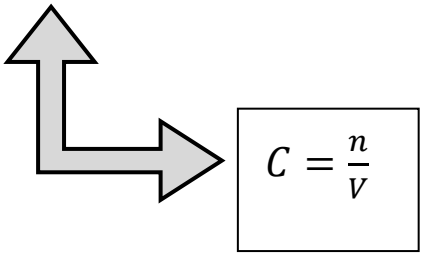
⑤ PARTS PER BILLION

$$parts\ per\ billion\ (ppb) = \frac{mass\ of\ solute}{mass\ of\ solution} \times 10^9$$

⑥ MOLARITY or MOLAR CONCENTRATION

$$\boldsymbol{molar\ concentration = C = \frac{moles\ of\ solute}{volume\ of\ solution\ in\ L}}$$





$$C = \frac{n}{V}$$

- Most commonly used form for concentrations

- ***Units***: $\frac{mol}{L} \iff M \iff mol \cdot L^{-1} \iff mol \cdot dm^{-3}$

EXAMPLES:

① If 0.90 grams of sodium chloride are dissolved in 40 mL of solution, what is...

A) the mass per volume percent? B) the molar concentration?

② 4.00 g of sodium phosphate is used to form a 300 mL aqueous solution. What is...

A) the mass to volume percent? B) the molar concentration?

③ TSP solution is 1.7 % (m/V). What mass of TSP is used to make a 3.5 L solution?

④ A 35.2 g sample of roadside slush is left to stand. After evaporation of the solvent, 6.35 g of residue consisted of calcium chloride. What is the m/m % of the salt?

⑤ Bronze contains 80% copper (m/m %). A sample of bronze has 42.6 g copper. What is the mass of bronze?

⑥ Rubbing alcohol has 70% (V/V %) isopropyl alcohol. How much isopropyl alcohol and water is used to make a 5.0 L solution?

⑦ 0.25 g of sodium chloride is dissolved to form a 100 mL aqueous solution. What is the concentration of the solution in ppm? ppb?

⑧ What is the molar concentration of a 200 mL aqueous solution containing 14.6 g NaCl?

⑨ 3.00 L of a 2.50 M sodium hydroxide solution is required. What mass of the solid is needed?

⑩ A container consists of 2.25 L of a 0.100 M solution of calcium nitrate. If a 40.0 mL sample is taken from the container, what mass of calcium nitrate is in the sample?

THE CHALLENGES!

⑪ 0.325 g of carbon dioxide gas is dissolved in 330 mL pop. What is the concentration...

A) in ppm? [assume density of pop = density of solvent.]

B) in molarity?

⑫ Sulfur dioxide is a pollutant in air. Safe levels of the pollutant is less than 325 ppm. A sample of air measured a concentration of $6.5 \times 10^{-6} M$. Is the air safe? [NOTE: density of air = 1.225 g/L]

⑬ 5% (m/m) ethanol (C_2H_5OH) in water is equivalent to what molar concentration?

⑭ Symptoms of mercury poisoning becomes apparent when a body ingests more than 20 mg of mercury.

A) Express this amount as ppm for a 2.5 kg fish.

B) Express this amount as % m/m.

⑮ The concentration of chlorine in a swimming pool is generally kept in the range of 1.4 to 4.0 ppm. A sample of water from a certain pool has a concentration of $1.50 \times 10^{-5} M$. Does the water contain a safe level of chlorine?

⑯ A stock solution of sulfuric acid (H_2SO_4) is 60% (m/v) in water. What is the molar concentration?