Chapter 7
Solutions

We’ve just looked at states of matter one at a time... now let’s combine two of them—or rather, let’s combine something, anything, with a liquid. For instance: add a pinch of table salt to a flask of water.

Alakazam! Alakazaride! Disappear sodium! Disappear chloride!

The salt, of course, completely vanishes.

It’s like magic! Um... isn’t it?

Magic is only magic if it’s unexpected...

The salt, as we say, dissolves in the water.
Say, where'd you come from, anyway?

The magic of cartooning.

When a substance dissolves in a liquid, the combination is called a solution. The liquid is the solvent, and the dissolved material is the solute.*

Solute + Solvent → Solution

A dissolved solid falls apart into its individual constituent particles, either ions or molecules. Gases also dissolve molecule by molecule. This explains why solutions are usually transparent.

Sugar—sucrose, $C_{12}H_{22}O_{11}$—breaks into whole molecules. (Water molecules like its OH groups.)

For example, sodium chloride, NaCl, dissociates in water into single Na$^+$ and Cl$^-$ ions, which bind with the water molecules.

Vinegar, a solution of acetic acid, $CH_3CO_2H$, contains hydrogen ions, H$,^+$, acetate ions, $CH_3CO_2^-$, and much $CH_3CO_2H$ still in combination.

*Actually, a solution can be solid or gaseous too. Any homogeneous mixture of two or more substances is considered a solution, whatever its phase.
Let's look more closely at the dissolving process. Imagine a chunk of material immersed in liquid. In order to dissolve, some of its particles must break the bonds that hold them together and form new bonds with molecules of liquid. Similarly, IMFs within the liquid must also be overcome.

Each free solute particle attracts one or more molecules of solvent, which cluster around it in a solvent “cage.” This process of breaking and forming bonds is called solvation.

All this bond rearranging means that dissolving is a chemical reaction. Among other things, then, it has an associated enthalpy change, which may be positive or negative.

For example, when magnesium chloride, MgCl₂, dissolves in water, it has an enthalpy of solvation

\[ \Delta H = 119 \text{ kJ/mol} \]

Highly endothermic! A mere 4 g of MgCl₂ (= .042 mol) in 50 mL (= 50 g) of water drops the water’s temperature by 23.9°C (by the basic calorimetry equation).

Chemical cold packs are in fact made from MgCl₂ and other salts that absorb heat when dissolved in water.

More on energy in the next chapter... but for now... I'm chillin’... ahhh...
SOME LIQUID MIXTURES ARE NOT SOLUTIONS:

WHEN I STIR POWDERED MILK INTO WATER, THE SOLID PARTICLES REMAIN IN VERY LARGE CLUMPS OF MOLECULES. A MIXTURE LIKE MILK IS CALLED A SUSPENSION, AND SUSPENSIONS ARE OPAQUE.

ANOTHER EXAMPLE WOULD BE PAINT, IN WHICH FLECKS OF PIGMENT ARE SUSPENDED IN OIL OR SOME GEL-LIKE MEDIUM.

AN EMULSION IS A SUSPENSION OF ONE LIQUID IN ANOTHER. MAYONNAISE, FOR EXAMPLE, MAINLY CONSISTS OF TINY DROPLETS OF OIL SUSPENDED IN VINEGAR. ORDINARILY, OIL AND VINEGAR WOULD SEPARATE, BUT THE ADDITION OF A SMALL AMOUNT OF MUSTARD AND EGG YOLK STABILIZES THE EMULSION.

LONG MOLECULES FROM THE YOLK BURROW INTO OIL DROPLETS. A POLAR “TAIL” STICKS OUT AND ATTRACTS THE POLAR WATER MOLECULES IN VINEGAR, WHICH BLOCK THE DROPLETS FROM MERGING.

FROM NOW ON, WE CONCENTRATE ON SOLUTIONS.

CONCENTRATE—GET IT?

I’M AFRAID SO...
Concentration

is a measure of how much solute is present in a solution relative to the whole.

For example, weigh out 35g of NaCl. Put it in a graduated container and add water until there is one liter of solution.

The concentration of this solution is 35 g/L and measures mass of solute per volume of solution.

Other possible measures (all used!):

- Mass of solute per mass of solution
- Volume of solute per volume of solution
- Mass of solute per volume of solvent (not the same thing as volume of solution!)
- Mass of solute per mass of solvent
- Parts per million (ppm) (a mass-per-mass ratio of very dilute solutions)
- Parts per billion (ppb, even more dilute)

When the solvent is water, we can easily convert from a mass-volume ratio to a mass-mass ratio, because one liter of water weighs one kilogram. A liter of very dilute aqueous solution, of course, weighs the same.
Our favorite measure of concentration actually tells you how many molecules are dissolved relative to volume. **Molarity**, or molar concentration, is the number of moles of solute per liter of solution. We write

\[ M = \text{moles/liter}. \]

Rats! No, moles!

What's the molarity of our 35 g/L salt solution? One mole of NaCl weighs 58.4 g, so we have

\[
\frac{35 \text{ g}}{58.4 \text{ g/mol}} = 0.6 \text{ mol NaCl}
\]

In a liter of solution, the molarity is 0.6 M.

We use square brackets, [ ], to denote molar concentration of any "species" (i.e., any particular molecule or ion) in solution. Here, since NaCl dissociates completely in solution,

\[
[\text{Na}^+] = 0.6 \text{M} \\
[\text{Cl}^-] = 0.6 \text{M}
\]

In a 1 M solution of Na₂SO₄, which also fully dissociates,

\[
[\text{Na}^+] = 2 \text{M} \\
[\text{(SO}_4^{2-}] = 1 \text{M}
\]

There are two moles of Na⁺ for each mole of Na₂SO₄.