# 6.1: What Is A Solution?

The first type of complex system that we will consider is a solution. You almost certainly already have some thoughts about what a solution is and you might want to take a moment to think about what these are. This will help you recognize your implicit assumptions if they "get in the way" of understanding what a solution is scientifically. The major difference between a solution and the systems we have previously discussed is that solutions have more than one chemical substance in them. This raises the question: what exactly is a solution and what does it mean to dissolve? You are probably thinking of examples like sugar or salt dissolved in water or soda. What about milk? Is it a solution? Do solutions have to be liquid or can they also include gases and solids? What is the difference between a solution and a mixture?

It turns out that we can make solutions from a wide range of materials. Although it is common to think of solutions in terms of a solid dissolved into a liquid, this is not the only type of solution. Other examples of solutions include: gas in liquid (where molecular oxygen, or $O_2$, dissolves in water – important for fish); solid in solid (the alloy brass is a solution of copper and zinc); gas in solid (hydrogen can be dissolved in the metal palladium); and liquid in liquid (beer is a solution of ethanol and water and a few other things).

Let us take a closer look at what we mean by a solution, starting with a two-component system. Typically, one of the components is present in a smaller amount than the other. We call the major component the solvent and the minor component(s) the solute(s). The most familiar solutions are aqueous solutions, in which water is the solvent. For example, in a solution of the sugar glucose in water, glucose molecules are the solute and water molecules are the solvent. In beer, which is typically 2–4% ethanol, ethanol is the primary solute and water is the solvent. Once they are thoroughly mixed, solutions have the same composition throughout—they are homogeneous at the macroscopic scale, even though at the molecular level we still find different types of molecules or ions. This is an important point: Once mixed, they remain mixed! If you take a sample from the top of a solution, it has the same composition as a sample from elsewhere in the solution. Solutions, when viewed at the molecular level, have the solute particles evenly (and randomly) dispersed in the solute. Also, because the solute and solvent are in contact with each other, there must be some kind of molecular interaction between the two types of molecules. This is not true for simple mixtures. For example, we tend to describe air as a mixture of gases ($N_2$, $O_2$, $H_2O$, etc.), rather than a solution because the gas molecules do not interact aside from the occasional collision with each other.

## Molecular Formation of Solutions

Let us consider a solution of ethanol and water. Many common solutions contain these two components (usually with minor amounts of other substances as well). Ethanol and water are soluble in each other (what is known as "miscible") in all proportions. For example, beer is typically about $3\%$ alcohol ($6\%$ proof),[1] wine about $6\%$ alcohol ($12\%$ proof), and liquors such as whiskey or brandy are about $50\%$ alcohol ($100\%$ proof). How do they dissolve into each other at the molecular level, and why?

For a process to be thermodynamically favorable, the Gibbs (free) energy change ($\Delta G$) associated with that process must be negative. However, we have learned that Gibbs energy change depends on both enthalpy ($H$) and entropy ($H$) changes in the system. It is possible to envision a wide range of situations – involving both positive and negative changes in $H$ and $S$, and we have to consider the magnitudes of the enthalpy, the entropy and the temperature changes.

So what happens when we add a drop of ethanol to a volume of water? The ethanol molecules rapidly disperse and the solution becomes homogeneous. The entropy of the ethanol–water solution is higher than that of either substance on its own. In other words, there are more distinguishable arrangements of the molecules when they are mixed than when they are separate. Using simple entropic arguments we might, at least initially, extend the idea to include all solutions. Everything should be soluble in everything else, because this would to an entropy increase, right? Wrong. We know that this is not true. For example, oil is not soluble in water and neither are diamonds, although for very different reasons. So what are the factors influencing solution formation? We will see that some are entropic (involving $\Delta S$) and some enthalpic (involving $\Delta H$.)

Questions

**Questions to Answer**

- Make a list of some common solutions you might encounter in everyday life. How do you know they are solutions and not mixtures?
- Consider a solution formed from 100 g of water and 5 g sodium chloride:
  - What would you expect the mass of the solution to be? Why?

- What would you expect the volume of the solution to be? Why?
- How would you test your hypotheses? What experiments would you do?
- What evidence would you collect?