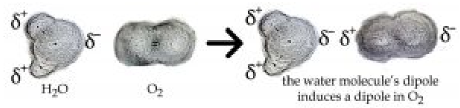
6.6: Temperature and Solubility

Can you also predict the effect of temperature on solubility? If you raise the temperature, does solubility of a solute increase or decrease? It would be reasonable to assume that increasing temperature increases solubility. But remember that both ΔH and ΔS have a role, and an increase in temperature increases the effect of changes in entropy. Dissolving solute into solvent is likely to increase entropy (if ΔS is positive), but this is not always the case. Consider what happens when you heat up water on the stove. Bubbles of gas are released from the liquid long before the water reaches its boiling point. At low temperatures, these bubbles contain air (primarily N_2, O_2) that was dissolved in the water.[10] Why? Because the solubility of most gases in water decreases as temperature rises. We can trace the reason for this back to the entropy of solution. Most gases have very small intermolecular attractions – this is the reason why they are gases after all. Gas molecules do not stick together and form solids and liquids. Therefore, they do not have very high solubility in water. As an example, the solubility of O_2 in water is $8.3\ mg/L$ (at $25^{\circ}C$ and 1 atmosphere).



Most gases have a slightly favorable (negative) enthalpy of solution and a slightly unfavorable (negative) entropy of solution. The effect on enthalpy can be traced to the dipole–induced dipole attractions formed when the gas dissolves in the solution. The decrease in entropy results from the fact that the gas molecules are no longer free to roam around – their positional entropy is more constrained within the liquid phase than it is in the gas phase. When the temperature is increased the gas molecules have more kinetic energy and therefore more of them can escape from the solution, increasing their entropy as they go back to the gas phase. Thus, the solubility of O_2 and other gases decreases as temperature increases. This can produce environmental problems, because less oxygen is available for organisms that live in the water. A common source of thermal pollution occurs when power plants and manufacturing facilities expel warm water into the environment.

Solutions of Solids in Solids: Alloys

Another type of solution occurs when two or more elements, typically metals, are melted and mixed together so that their atoms can intersperse, forming an alloy. Upon re-solidification, the atoms become fixed in space relative to each other and the resulting alloy has different properties than the two separate metals. Bronze was one of the first known alloys. Its major component is copper (~ 90) and its minor component is tin (~ 10), although other elements such as arsenic or phosphorus may also be included.

The Bronze Age was a significant leap forward in human history.[11] Before bronze, the only metals available were those that occurred naturally in their elemental form—typically silver, copper, and gold, which were not well suited to forming weapons and armor. Bronze is harder and more durable than copper because the tin atoms substitute for copper atoms in the solid lattice. Its structure has stronger metallic bonding interactions, making it harder and less deformable, with a higher melting point than copper itself. Artifacts (weapons, pots, statues, etc.) made from bronze are highly prized. Before bronze, the only metals available were those that occurred naturally in their elemental form– typically silver, copper, and gold.

Steel is another example of a solid–solid solution. It is an iron solvent with a carbon solute. The carbon atoms do not replace the iron atoms, but fit in the spaces between them; this is often called an interstitial alloy. Because there are more atoms per unit volume, steel is denser, harder, and less metallic than iron. The carbon atoms are not in the original lattice, so they affect the metallic properties more and make it harder for the atoms to move relative to each other. Steel is more rigid, less malleable, and conducts electricity and heat less effectively than iron.

Is the Formation of a Solution a Reaction?

We have not yet considered what happens during a chemical reaction: a process where the atoms present in the starting material are rearranged to produce different chemical species. You may be thinking, “Isn’t the formation of a solution a chemical reaction?” If we dissolve ethanol in water, does the mixture contain chemically different species than the two components separately? The answer is no: there are still molecules of ethanol and molecules of water. What about when an ionic substance dissolves in water? For example, sodium chloride must separate into sodium and chloride ions in order to dissolve. Is that a reaction? Certainly interactions are broken (the interactions between Na^+ Cl^- ions) and new interactions are made (between Na^+ ions and water and Cl^- ions and water), but the dissolution of a salt has not traditionally been classified as a reaction, even though it seems to fit the criteria.[12] Rather than quibble about what constitutes a reaction, let us move along the spectrum of possible changes and look at what happens when you dissolve a molecular species in water and it forms ions.

When you dissolve hydrogen chloride, HCl (a white, choking gas), in water you get an entirely new chemical substance: hydrochloric acid (or muriatic acid as it is known in hardware stores), one of the common strong acids. This reaction can be written:

$$HCl(g) + H_2O \rightarrow HCl(aq) \tag{6.6.1}$$

This is a bit of shorthand because we actually begin with lots of water, but not much of it is used in the reaction. We indicate this fact by using the aq symbol for aqueous, which implies that the HCl molecules are dissolved in water (but as we will see they are now no longer molecules). It is important to recognize that hydrochloric acid, $HCl(aq)$, has properties that are quite distinct from those of gaseous hydrogen chloride $HCl(g)$. The processes that form hydrochloric acid are somewhat similar to those that form a solution of sodium chloride, except that in this case it is the covalent bond between H and Cl that is broken and a new covalent bond between H and O is formed at the same time.

$$HCl(g) + H_2O \rightarrow H_3O^+ + Cl^- \tag{6.6.2}$$

We call this reaction an acid–base reaction. In the next chapter, we will consider this and other reactions in (much) greater detail.

Questions

Questions to Answer

Can you convert the solubility of O_2 in water into molarity (moles solute (O_2) / liter solution)?

If solubility of gases depends on dipole–induced dipole interactions, what do you think the trend in solubility is for the noble gases (He, Ne, Ar, Kr, Xe)?

What else might increase the solubility of a gas (besides lowering the temperature)? (Hint: How are carbonated drinks bottled?)

Why do you think silver, copper, and gold often occur naturally as elements (rather than compounds)?

Draw an atomic-level picture of what you imagine bronze looks like and compare it to a similar picture of steel.

Use these pictures to explain the properties of bronze and steel, as compared to copper and iron.

Questions to Ponder

- Why do you think the Iron Age followed the Bronze Age? (Hint: Does iron normally occur in its elemental form? Why not?)
- How did the properties of bronze and steel influence human history?