Polar compounds tend to dissolve in water, and we can extend that generality to the most polar compounds of all—ionic compounds. Table salt, or sodium chloride (NaCl), the most common ionic compound, is soluble in water (360 g/L). Recall that NaCl is a salt crystal composed not of discrete NaCl molecules, but rather of an extended array of Na⁺ and Cl⁻ ions bound together in three dimensions through electrostatic interactions. When NaCl dissolves in water, the electrostatic interactions within the crystal must be broken. By contrast, when molecular compounds dissolve in water, it is the intermolecular forces between separate molecules that are disrupted. One might imagine that the breaking of ionic interactions would require a very high-energy input (we have already seen that diamonds do not dissolve in water because actual covalent bonds have to be broken). That would be true if all we considered was the energy required to break the ionic interactions, as indicated by the fact that NaCl melts at 801 oC and boils at 1413 oC. But we know that substances like NaCl dissolve readily in water, so clearly there is something else going on. The trick is to consider the whole system when NaCl dissolves, just like we did for molecular species. We need to consider the interactions that are broken and those that are formed. These changes in interactions are reflected in the ΔH term (from ΔG = ΔH – TΔS).

When a crystal of NaCl comes into contact with water, the water molecules interact with the Na⁺ and Cl⁻ ions on the crystal’s surface, as shown in the figure. The positive ends of water molecules (the hydrogens) interact with the chloride ions, while the negative end of the water molecules (the oxygen) interacts with the sodium ions. So the ion on the surface of the solid interacts with water molecules from the solution; these water molecules form a dynamic cluster around the ion. Thermal motion depicting the hydration of a Na⁺ (which reflects the kinetic energy of the molecules, that is, the + ion on a NaCl surface) then moves the ion and its water shell into solution. The water shell is highly dynamic—molecules are entering and leaving it. The ion–dipole interaction between ions and water molecules can be very strongly stabilizing (−ΔH). The process by which solvent molecules interact with and stabilize solute molecules in solution is called solvation. When water is the solvent, the process is known as hydration.

Questions to Answer

• Draw a molecular-level picture of a solution of NaCl. Show all the kinds of particles and interactions present in the solution.

• When we calculate and measure thermodynamic quantities (such as ΔH, ΔS and ΔG), why is it important to specify the system and the surroundings?

• When a substance dissolves in water, what is the system and what are the surroundings? Why? What criteria would you use to specify the system and surroundings?
• For a solution made from NaCl and water, what interactions must be overcome as the NaCl goes into solution? What new interactions are formed in the solution?

• If the temperature goes up when the solution is formed, what can we conclude about the relative strengths of the interactions that are broken and those that are formed? What can we conclude if the temperature goes down?

• When you measure the temperature of a solution, are you measuring the system or the surroundings?

Questions to Ponder

• Why is the water shell around an ion not stable?

• What are the boundaries of a biological system?

References

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