The importance of water for high fidelity information processing and for life

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Is water an absolute prerequisite for life? Life depends on a variety of non-covalent interactions among molecules, the nature of which is determined as much by the solvent in which they occur as by the molecules themselves. Catalysis and information processing, two essential functions of life, require non-covalent molecular recognition with very high specificity. For example, to correctly reproduce a string consisting of 600,000 units of information (e.g., 600 kilobases, equivalent to the genome of the smallest free living terrestrial organisms) with a 90% success rate requires specificity > 10^7:1 for the target molecule vs. incorrect alternatives. Such specificity requires (i) that the correct molecular association is energetically stabilized by at least 40 kJ/mol relative to alternatives, and (ii) that the system is able to sample among possible states (alternative molecular associations) rapidly enough to allow the system to fall under thermodynamic control and express the energetic stabilization. We argue that electrostatic interactions are required to confer the necessary energetic stabilization vs. a large library of molecular alternatives, and that a solvent with polarity and dielectric properties comparable to water is required for the system to sample among possible states and express thermodynamic control. Electrostatic associations can be made in non-polar solvents, but the resulting complexes are too stable to be "unmade" with sufficient frequency to confer thermodynamic control on the system. An electrostatic molecular complex representing 3 units of information (e.g., 3 base pairs) with specificity >10^7 per unit has a stability in non-polar solvent comparable to that of a carbon-carbon bond at room temperature. These considerations suggest that water, or a solvent with properties very like water, is necessary to support high-fidelity information processing, and can therefore be considered a critical prerequisite for life.