Is Water a Universal Solvent for Life?

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There are strong reasons to believe that the laws, principles and constraints of physics and chemistry are universal. It is much less clear how this universality translates into our understanding of the origins of life. Conventionally, discussions of this topic focus on chemistry that must be sufficiently rich to seed life. Although this is clearly a prerequisite for the emergence of living systems, I propose to focus instead on self-organization of matter into functional structures capable of reproduction, evolution and responding to environmental changes. In biology, most essential functions are largely mediated by non-covalent interactions (interactions that do not involve making or breaking chemical bonds). Forming chemical bonds is only a small part of what living systems do.

There are specific implications of this point of view for universality. I will concentrate on one of these implications. Strength of non-covalent interactions must be properly tuned. If they were too weak, the system would exhibit undesired, uncontrolled response to natural fluctuations of physical and chemical parameters. If they were too strong kinetics of biological processes would be slow and energetics costly. This balance, however, is not a natural property of complex chemical systems. Instead, it has to be achieved with the aid of an appropriate solvent for life. In particular, potential solvents for life must be characterized by a high dielectric constant to ensure solubility of polar species and sufficient flexibility of biological structures stabilized by electrostatic interactions. Among these solvents, water exhibits a remarkable trait that it also promotes solvophobic (hydrophobic) interactions between non-polar species, typically manifested by a tendency of these species to aggregate and minimize their contacts with the aqueous solvent. Hydrophobic interactions are responsible, at least in part, for many self-organization phenomena in biological systems, such as the formation of cellular boundary structures or protein folding. Strengths of electrostatic and hydrophobic interactions are similar and can be balanced over a wide range of temperatures, which considerably increases the repertoire of interactions that can be used to modulate biological functions.

Some properties of water, e.g. its chemical activity against polymerization reactions, are considered as unfavorable to life. In actuality, this might be a favorable trait because life requires a balance between constructive and destructive processes. For example, molecules synthesized in response to specific conditions must be degraded once these conditions change. Otherwise regulation of biological processes would be virtually impossible.

Water might not be the only liquid with favorable properties for supporting life. It has been proposed that formamide, which might be present elsewhere in the universe in sufficient quantities to warrant interest, could be a potential alternative to water for the

origin of life. However, this will remain highly hypothetical until it is demonstrated in further studies on its physical, chemical and biological properties it is capable of mediating self-organization of matter and providing proper balance between different types of non-covalent interactions.