Phosphate Ester Bond Chemistry with Zirconium (IV) Catalysts

Nathaniel Bunnell

The following is an excerpt from a longer piece. For full text, please visit https://scholar.colorado.edu/concern/undergraduate_honors_theses/cf95jc857

Abstract

Earth's infancy was a time of immense chemical complexity. Over millions of years, steady chemical cycles were formed and driven by thermodynamics and organic precursors left over from the planet's formation. In aqueous environments, this chemistry may have led to the formation of catalytic RNA species capable of information storage and replication. Presumably, the construction of these oligonucleotides was catalyzed by primordial Earth's abundant mineral content. However, the species that accelerated these types of transformations are unknown. This study explored the role of Zr+4 in the catalytic formation of phosphate ester bonds. Through TLC screening, it was found that most of the test conditions produced no observable phosphorylated products. In the final samples, highly polar spots may have contained phosphate-bearing compounds. These findings provide mixed certainty about zirconium's catalytic capacity for ester formation but suggest that zirconium metal-organic frameworks (MOFs) and alternative metal ions may be viable routes for future investigation.

Lay Summary

Earth began as a planet of rock and magma, hardly recognizable without the biological adornments that characterize it today. For nearly a billion years, consistent comet and asteroid impacts heated the planet and vaporized any reservoirs of water or organic matter that covered the surface. As this bombardment subsided, life came to fruition in half the time that the mineral rain had lasted. The question of how this transition occurred is one of the most elusive in the biochemical field. In particular, it is still unknown how all life, whether primordial or modern, came to share polynucleotides as an essential coding system for all their requisite biological functions.

This study explored the role of Zr+4, an abundant mineral on early Earth, in the catalytic formation of phosphate ester bonds, the core linkages in DNA and RNA. Through TLC screening, it was found that most of the test conditions produced no observable phosphorylated products. In the final samples, highly polar spots may have contained phosphate-bearing compounds. These findings provide mixed certainty about zirconium's capacity for ester formation but suggest that zirconium metal-organic frameworks (MOFs) and alternative metal ions that reflect early Earth's composition may be viable routes for future investigation into this grand mystery.