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Nitrogen Heterocycles in Miller-Urey Spark-Discharge Mixtures: Using Chemical Trends to Elucidate Plausible pre-RNAs on the Early Earth

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Introduction: Although it is thought that RNA preceeded DNA as the first genetic material, the prebiotic synthesis of RNA has yet to be demonstrated [1]. The difficulty in RNA synthesis under prebiotic conditions has led to the opinion that RNA may have been preceeded by a simpler genetic molecule (i.e., a pre-RNA) [2]. Numerous studies have synthesized potential pre-RNAs in the lab, but the synthesis of their monomers and their subsequent polymerization remains unresolved [3]. A more tenable approach to identify plausible pre-RNAs may be to determine the chemical fate of nitrogen heterocycles in a prebiotic environment. Nitrogen heterocycles are of particular interest because they may have been available on the early Earth and are the means by which DNA, RNA, and by extension, likely any pre-RNA, can store information [4-6].

Methodology: The reactivity of 53 nitrogen heterocycles was explored in mixtures produced from a Miller-Urey spark-discharge apparatus. Spark-discharge experiments were carried out in the presence of water (pH 8) under two 1 bar atmospheres: (1) a reducing atmosphere of 40% N_2, 10% CO_2, 25% H_2, and 25% CH_4 and (2) a neutral atmosphere of 50% N_2 and 50% CO_2. The resulting mixture was incubated with a single heterocycle at 80°C and analyzed using a high resolution linear ion trap orbitrap hybrid mass spectrometer with a direct analysis in real-time ion source. Adducts and their mechanism of synthesis were confirmed by incubating heterocycles in solutions of plausible reactants and analyzing via MSMS and nuclear magnetic resonance.

Results: The most common products appeared to be due to reactions between nitrogen heterocycles and cyanoacetylene, glycolonitrile, acrylonitrile, cyanide and their hydrolysis products. Interestingly, each of these reactants are known to spontaneously polymerize in solution, and may therefore represent the first step towards building some type of pre-RNA structure.

When heterocycles are incubated with acrylic acid and glycolonitrile they yield propanoic acid (R-CH_2CH_2COOH) and acetamide (R-CH_2CONH_2) adducts. Eventually the acetamide adduct will hydrolyze to form acetic acid. Heterocycles with acetic acid adducts have been proposed as the heterocycle unit for the pre-RNA, Peptide Nucleic Acid (PNA). PNA is a polymer with a N-(2-aminoethyl)glycine (AEG) backbone. Given that AEG has been identified in spark-discharge mixtures [7], our results demonstrate the one-pot synthesis for the components of PNA under prebiotic conditions. Ongoing work includes an effort to determine whether heterocycles with acetamide and propanoic acid adducts can attach to AEG to form a PNA monomer.

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