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The Phosphorus Problem in the Pre-biotic World

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The so-called "phosphorus problem" in prebiotic life has traditionally been framed in terms of phosphate solubility. Phosphates (PO_4^{3-}) are generally insoluble and therefore cannot supply adequate nutrients for protocellular metabolism. Phosphite (HPO_3^{2-}) is thought to solve this problem, but introduces a new obstacle, what might be termed the "phosphorus permeability problem". Phosphate and phosphite are both charged at circumneutral pH and cannot cross a lipid membrane. No evolutionary pressure exists to drive formation of transporters prior to the existence of a membrane, and so the first protocells likely lacked transporters. We suggest that volatile forms of phosphorus -- phosphine (PH_3) and diphosphane (P_2H_4) – may play a key role in prebiotic phosphorus metabolism. We show that volatile phosphorus species are produced during the aqueous reaction of Fe_3P, an analog to meteoritic schreibersite ($(Fe,Ni)_3P$). Using quantitative structure-activity relationship (QSAR) and membrane permeation models, we show that PH_3 and P_2H_4 can efficiently diffuse passively across cell membranes without the need for transporters. We further constrain the solubility and membrane permeation of phosphite and its calcium and magnesium salts. These results indicate that volatile phosphorus species may be key components of the global P cycle on early Earth and in the origin of life.