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Constructing Free Energy Maps of Oligomerization Reactions in Solution

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Introduction: Oligomerization is a key reaction for building complexity in the chemical origins of life. For example, sugars are oligomers of formaldehyde, the nucleobase adenine is a pentamer of HCN, short peptides are oligomers of amino acids, and small RNA molecules are nucleotide oligomers. However, in a complex broth of chemical moieties, would self-oligomerization, co-oligomerization or other chemical reactions dominate? What are the factors that may influence the product distribution as small prebiotic molecules react with each other to form larger molecules? Could such chemical broths generate a proto-metabolic cycle?

What we have done: Our approach to answering these questions is to systematically construct free energy maps for the reactions of prebiotically plausible molecules in solution. A computational protocol was developed based on studying the self-oligomerization of small water-soluble aldehydes [1-2]. We tested our protocol by predicting the equilibrium concentrations of a 1 M solution of glycolaldehyde and found excellent agreement with experimental NMR results [3]. The protocol was subsequently applied to studying the self-oligomerization of CH_2O [4] the co-oligomerization of CH_2O and NH_3 [5], and the reactions of HCN and NH_3 [6]. In all these cases, we calculated the reaction free energies (from first principles) of all potential stable molecules and intermediates, and also transition states connecting stable species. This allowed us to construct a free energy map detailing the thermodynamics and kinetics in systems of molecules with their corresponding oligomers in aqueous solution under standard conditions.

What we are doing: At present, we are investigating if our protocol can be extended to a wider range of systems Current work includes studying the interactions in a CH_2O + HCN + NH_3 H_2O system, co-oligomerization of CH_2O and pyrrole en route to porphyrin rings, and replacement of ester bonds with amide bonds in oligomers of glycolic acid and glycine [7], motivated by the experimental work of Forsyth et al. [8]. While our previous calculations aimed at generating a baseline free energy map for pH 7 and 25^{o}C, we are exploring modifications to our protocol to take into account varying pH, temperature and concentration. This presentation will summarize our recent progress and discuss challenges as we extend our model to a wider range of environments that may have been present in the prebiotic milieu.

References:

[1] Kua J et al. (2008) *Journal of Physical Chemistry A* 112:66–72.

[2] Krizner HE et al. (2009) *Journal of Physical Chemistry A* 113:6994–7001.

[3] Kua J et al. (2013) *Journal of Physical Chemistry A* 117:2997–3008.

[4] Kua J et al. (2013) *Journal of Physical Chemistry A* 117:12658–12667.

[5] Kua J et al. (2015) *Journal of Physical Chemistry A* 119:2122-2131.

[6] Kua J and Thrush KL (2016) *Journal of Physical Chemistry B* 120:8175–8185.

[7] Kua J and Sweet LM (2016) *Journal of Physical Chemistry A* 120:7577-7588.

[8] Forsyth et al. (2015) *Angewandte Chemie International Edition* 54:1-6.