Heterogeneous Protocells: Membrane Properties and Compartmentalization

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Introduction: Understanding of the evolution of protocell membranes and their transition to biological membranes is an important study to understand the chemical origins of life.[1] It has been known that small and medium chain fatty acids (C9-C16) are found in carbonaceous meteorites and these fatty acids are capable of forming bilayer membrane structures called protocells.[2] These protocells can act as compartmentalization for small and macromolecules by offering unique environments within a protocell. Therefore, it is important to understand these protocells membrane stability and dynamics. Homogenous short-chain fatty acid-based protocells (C9-C12) are capable of forming protocells, however these short-chain homogenous fatty acid protocells have a narrow range of stability towards pH, temperature, metal ion concentrations.[3-4] Since primitive earth conditions offers a heterogeneous mixture of small molecules, herein, we have studied the membrane properties of heterogeneous mixture of C10 fatty acid-based protocells and also showed a natural transition of C10 fatty acid systems to phospholipid systems under plausible prebiotic conditions (Figure 1).[5]

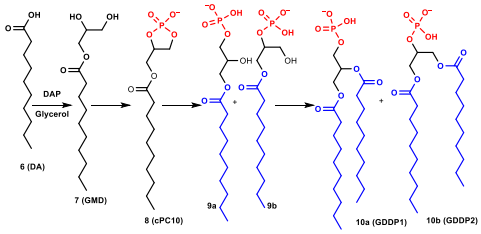

Figure 1: A natural emergence of heterogeneous mixture of mono- and di-acyl glycerol phospholipids from the mixture of decanoic acid, glycerol and DAP.

C10 cyclic phosphate-based heterogeneous mixture:[5] Decanoic acid (DA) forms protocells (vesicles) in water at pH 6.5-7.5, near its pKa, but not stable to wide range of pH, temperature and divalent metal ions. However, the mixture of DA and C10 cyclic phosphate (cPC10) forms stable vesicles at broad range of pH (4.0-6.6) and di-valent metal ion (Mg^{2+} and Ca^{2+}) concentrations up to 25 mM. Whereas, the mixture of glycerol monodecanoate (GMD) and cPC10 showed robust stability over a range of pH (5.0-8.0) and stable to di-valent metal ion (Mg^{2+} and Ca^{2+}) concentrations up to 0.1 M. The extra stability attained by the mixture of GMD:cPC10 (5:1) is due to the less charge and more hydrogen bonding compared to the mixture of DA:cPC10 (2:1). Both 2:1 DA:cPC10 and 5:1 GMD:cPC10 are capable of encapsulating the small molecules (e.g. AF488 dextran 10Kda) effectively (>65%) over 2 days (Figure 2).

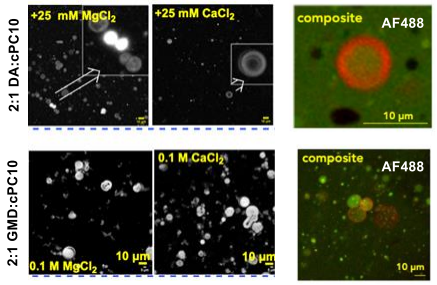

Figure 2: Stability and encapsulation (AF488) of 2:1 DA:cPC10 and 5:1 GMD:cPC10 towards the di-valent metal ions.

Feasibility of protometabolic reactions within protocells: Since the protocells can as compartmentalization of small molecules, we are interested in studying the protometabolic reaction of pyruvate and glyoxylate within protocells to replicate the plausible prebiotic cell compartmentalized reactions. Herein, we successfully developed various techniques, LC-MS, ^{13}C-NMR and HPLC coupled with fluorescence to analyze the α-ketoacids within protocells. As this is an ongoing work, we are currently working on the quantification of the products, permeation of α-ketoacids using the developed techniques.

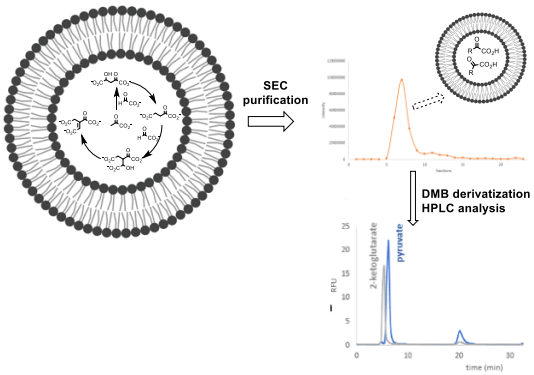

Figure 3: HPLC analysis of vesicles containing α-ketoacids.

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