Processes that Drove the Transition from Chemistry to Biology: Concepts and Evidence

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Two properties are particularly germane to the transition from chemistry to biology. One is the emergence of complex molecules (polymers) capable of performing non-trivial functions, such as catalysis, energy transduction or transport across cell walls. The other is the ability of several functions to work in concert to provide reproductive advantage to systems hosting these functions. Biological systems exhibit these properties at remarkable levels of efficiency and accuracy in a way that appears effortless. However, dissection of these properties reveals great complexities that are involved. This opens a question: how a simple, ancestral system could have acquired the required properties? Other questions follow. What are the chances that a functional polymer emerges at random? What is the minimum structural complexity of a polymer to carry out a function at a reasonable level of efficiency? Can we identify concrete, protobiologically plausible mechanisms that yield advantageous coupling between different functions? These and similar questions are at the core of the main topic of this session: how soulless chemistry became life?

Clearly, we do not have complete answers to any of these questions. However, in recent years a number of new and sometimes unexpected clues have been brought to light. Of particular interest are proteins because they are the main functional polymers in contemporary cells. The emergence of protein functions is a puzzle. It is widely accepted that a well-defined, compact structure (fold) is a prerequisite for function. It is equally widely accepted that compact folds are rare among random amino acid polymers. Then, how did protein functionality start? According to one hypothesis well folded were preceded by their poorly folded, yet still functional ancestors. Only recently, however, experimental evidence supporting this hypothesis has been presented. In particular, a small enzyme capable of ligating two RNA fragments with the rate of 10^6 above background was evolved *in vitro*. This enzyme does not look like any contemporary protein. It is very flexible and its structure is kept together just by a single salt bridge between a charged residue and a coordinating zinc. A similar picture emerges from studies of simple transmembrane channels that mimic those in ancestral cells. Again, they are extremely flexible and do not form a conventional pore. Yet, they efficiently mediate ion transport. Studies on simple proteins that are on-going in several laboratories hold promise of revealing crucial links between chemical and biological catalysis and other ubiquitous cell functions.

Interaction between composition, growth and division of protobiologically relevant vesicles and metabolic reactions that they encapsulate is an example of coupling between simple functions that promotes reproduction and evolution. Recent studies have demonstrated possible mechanisms by which vesicles might have evolved their composition from fatty acids to phospholipids, thus facilitating a number of new cellular functions. Conversely, it has been also demonstrated that an encapsulated metabolism might drive vesicle division. These are, again, examples of processes that might have driven the transition from chemistry to biology.