“Disciplined Disorder and Disordered Disciplines: Themes in the Emerging Science of Matter.”

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Ideas concerning elementary excitations above a simple ground state, first order phase transitions and continuous transitions with strongly fluctuating order parameters dominated the science of matter in the late 20th century. A new set of ideas began to emerge towards the end of the century which highlighted the role of a diversity of long-lived states- an energy landscape. The diversity of long-lived states was first argued to be a result of disorder, in the context of spin glasses. Yet a constructive theory of structural glasses, where the “disorder” is self-generated has been shown to explain many mysterious observations about such glasses using the idea of a mosaic of energy landscapes. In this theory, well-known empirical correlations of kinetics and thermodynamics are quantitatively reproduced without adjustable parameters. A new picture of the nature of “elementary excitations” in glasses also emerges when the theory is treated semi-classically. A complete quantum theory of diversity is still needed.

Biology is replete with a diversity of long-lived states. Energy landscape ideas have been used for describing the dynamics of folded proteins and to explain the process of folding itself. Biomolecular energy landscapes have many of the features of those for glasses but are simpler in some respects and more organized. This is a result of the discipline that natural selection imposes on stochastic molecular evolution. For the folding process to occur efficiently the landscape must be funneled, but other organized landscapes are needed for function e.g. for allostery, multiple discrete states are needed.

As we consider larger biomolecular assemblies, activation barriers rise, allowing (and requiring) nonequilibrium dynamics and assembly to dominate. Therefore, gene networks and cytoskeletons may be “jammed” systems.

As the exploration of biomolecular landscapes continues we will learn to synthesize matter with complex but organized landscapes. How will we describe these systems? Will we be able to describe them even far from equilibrium in a general way? Or does a specific machine-like behavior preclude universality? Will it make any sense to quantize these systems? Is “Quantum Life” a possibility?