Complex Adaptive Matter on the Nanometer to Micron Scale in Biological Physics

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I work on a wide variety of biological physics issues, ranging from energy transport in proteins on the picosecond time scale to microfabrication for biotechnology. In all the wide array of subjects I study, the conformational dynamics and sometimes the overt non-linearities of the systems I study play an important role. On the picosecond time scale and nanometer length scale I am interested in how highly specific, localized vibrational states of specific groups on a protein become delocalized and transport energy through the protein structure, if indeed this is what happens in energy transduction. On the nanometer length scale and microsecond time scale I am interested in how proteins are able to collapse down from random configurations into the basin of native conformations. On the micron scale and second time scale I am interested in how cell membranes, controlled by a complex array of cytoskeletal control features, are able to initiate sticking and locomotion of white blood cells of the immune system. Biotechnology and microfabrication brings a wealth of materials issues involving complex matter response, from the self-sealing nature of silicone elastomers to "smart materials" which can be used to act as transient gates and switches in lab on a chip devices.

Institute for Complex Adaptive Matter

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The rationale for the establishment of the institute is to create an entity that is unique in its structure and its goals. The time is ripe to propose a new vision for science underlying complex matter. In the past decades, one has seen significant conceptual breakthroughs brought about through research on complex matter. Such breakthroughs are attracting an increasingly large number of talented young researchers into the field. The role of the institute could be to nurture such talents and to further our knowledge of complex collective phenomena as a whole.

I would like to see the extent to which problems involving multiple length and time scales can be understood in a rigorous manner. Problems that can be understood on the basis of single length and time scales do not constitute the most challenging problems for the future. They are all essentially solved problems. Both problems in biology and complex electronic materials involve scales that span many logarithmic decades. Is it possible to capitalize on our understanding of phase transitions and the renormalization group, both classical and quantum, to solve new problems? Can we see simplicity emerging as classes of fixed points? Can spectroscopy with a wide dynamic range elucidate questions regarding multiple time scales?

For its success it is necessary to realize that this institute should be totally integrated with the fabric of the academic community. It should involve student training in a significant manner. There are few high class institutes that are student friendly and this is a great drawback. We have the unique opportunity, for example, to interact with the University of California as a whole. The students will be able to come in contact with the state of the art research at early stages of their careers. The field of complex physical systems is so diverse that it is impossible to train students by a single individual. In this respect, the institute can serve a valuable educational purpose and would be meaningful to the mission of the universities. I favor a distributed approach in which branches of the institute are built at a selected set of campuses. This gives the system the greatest flexibility and enhances the participation of different campuses.

As to a possible workshop, I would be interested in a broad workshop of biologists and condensed matter physicists. I am interested in finding out from the biologists the extent to which collective phenomena plays an important role in the function of the brain. I am sure they will be interested in our ability to deal with strongly interacting many degrees of freedom.

ICAM Theme

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During the past decade, coherent ultrafast nonlinear optical spectroscopy has become a sensitive experimental tool for studying many--body correlations. The two--level system models, often used to interpret such experiments in atomic systems, cannot explain qualitative features in the nonlinear dynamical response of semiconductor quantum wells. The interpretation of such features retains the challenge of the many--body problem, i.e., how to explain and predict properties of systems possessing many degrees of freedom in terms of their fundamental interactions.

Given the complexity of describing the femtosecond time evolution of such systems, arising from interactions among, e.g., optically—excited and Fermi sea carriers, a hierarchy of successive approximations has been formulated. To lowest order, this corresponds to the time-dependent Hartree-Fock approximation (Semiconductor Bloch Equations), which treat the interactions at the mean--field level. Pronounced features in the amplitude and phase dynamics of the nonlinear polarizations have been attributed to correlation effects beyond this mean field level. These cannot be treated within the usual effective lifetime and quasi--equilibrium (Markovian) approximations. During the past few years, there is an ongoing theoretical effort aimed at describing phenomena at the femtosecond time scale that arise from non--perturbative many--body effects.

The role of non-equilibrium correlations in the femtosecond time evolution of the coherent nonlinear optical spectra presents a many--body problem at the frontier of Condensed Matter Physics. Furthermore, the importance of analogous correlations in biological, molecular, and atomic systems make this topic truly interdisciplinary and a suitable theme for ICAM.

Synthesis Challenges and Strategies – Integrated Molecular Systems

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We are all fascinated with the exquisite design, construction, and function of natural materials like photosynthesis centers that very efficiently harvest light and sea shells that are simultaneously hard, tough, strong, and light weight. However from a materials perspective there are a number of synthetic challenges limiting our ability to impart to 'engineering' materials the functional characteristics of natural systems. For example, how to efficiently combine hard and soft materials to arrive at robust devices wherein hard materials serve as a scaffolding to stabilize, orient, and mediate the performance of soft materials. Recently we devised a self-assembly strategy to co-organize inorganic (I) and organic (O) precursors into a variety of hybrid organic (polymer)-inorganic nanocomposites prepared with 1-, 2-, or 3-dimensional connectivity of the constituent phases. We used micelle formation to spatially partition and organize organic precursors (within the hydrophobic micellar interiors) *and* inorganic precursors (surrounding the hydrophilic micellar exteriors). Further self-organization of the micellar species into liquid crystalline mesophases efficiently organizes the organic and inorganic precursors into desired I/O nanocomposite forms. For example, in an attempt to mimic the nanolaminated construction of mollusk shells, we combined soluble silica, methacrylate monomers, thermal initiators, and a silane coupling agent ($R'Si(OR)_3$ in an alcohol/water solvent. Preferential alcohol evaporation during dip-coating caused the partitioning of the hydrophobic monomers and initiators into the micellar interiors. Further evaporation induced self-organization of a lamellar mesophase created hundreds of alternating I/O layers in a single step. Thermally-initiated organic polymerization combined with continued inorganic polymerization locked-in the nanocomposite architecture and covalently bonded the organic-inorganic interface, resulting in the first self-assembled I/O nanolaminate.