University of Louisville Grand Challenge

Soft Matter Fundamentals for the Understanding and Enhancement of Life

Example Research/Scholarship Thrusts

- Drug delivery: Self-assembled nanoparticles with improved cell transmembrane transport
- Understanding Life: Dynamic self-assembly with bacterial swarms and protein motors; physical principles of cellular locomotion and intracellular transport
- Smart textiles: Embedding sensing, actuating, energy harvesting, thermally/environmentally responsive functions in clothing and other flexible fabrics
- Smart fluids: e.g. bullet proof fluids that instantly harden on impact; phase change materials that store enormous amounts of thermal energy
- Biomimicry of Adhesion: Structural biological studies of gecko feet and anti-wetting properties of lotus leaves plus adaptation of principles into engineered materials
- Laboratory on a chip: Mixing, sorting, reacting in a small volume; disposable bedside medical tests
- Understanding mechanical properties of soft tissue
- Bottom up molecular self-assembly based on DNA, macromolecules, colloids, block-copolymers
- Innovative methods of recovery and elimination of plastics and polymers from streams, lakes and oceans

Note: *This apparently disparate list of uses of soft matter is unified by a much smaller set of few fundamental principles. But given the numerous applications, a well organized group of faculty can both broaden the understanding of the possibilities inherent in this field, as well as serve as a focal point for supporting the endless areas of research at the University of Louisville that can benefit from the soft matter viewpoint.*

Soft Matter Research Grand Challenge

An emergent area of interdisciplinary research nationally and at UofL

Soft Matter Research is the study of deformation, flow, organization and self-assembly of materials that are soft, squishy and easily deformable; e.g., simple liquid solvents, liquid suspensions of small colloidal particles, oil-water suspensions, foams, lipid bilayers (and by extension, cell membranes), solutions of dissolved polymers, liquid crystals, gels and ultra-stretchy “elastomeric” rubbers. In these systems a small number of physical properties (e.g. surface tension, pressure, gravity, viscosity, temperature, entropy), chemical functionality (e.g. charge, hydrophilicity, hydrophobicity, dipole moment) and macromolecular structure (e.g. linear chain polymer, branched polymer, block copolymer, crosslinked gel, micelles) combine in a myriad of different ways to produce many unusual and unexpected material properties and effects. For instance,

- colloidal solutions have been demonstrated that instantly harden when shot with bullets, providing greater protection than current Kevlar bullet-proof vests
- special polymers have been included in motor oils that increase, rather than decrease, the viscosity as the polymer chains break down
- microscale roughness texturing has been used to make surfaces much less wetting, to almost all liquids, than even Teflon
- gradients in temperature, electrical field or wettability can be used to controllably move liquid droplets over defined paths, and even uphill.[3]

Improved understanding of the behavior of soft matter continues to be of great importance to major industrial sectors including personal care products (e.g. Proctor Gamble—for its creams, gels, conditioners, detergents, etc.), the food industry, plastics manufacture, oil and mineral refining. Numerous companies are being spun off with the goal of applying microfluidic devices and systems, devices developed with an understanding of soft matter principles, to various areas in rapid throughput medical testing, cell sorting, pharmaceutical development and bedside testing.

It is also important to recognize that soft matter principles are a central component of biophysical research at all scale sizes, from bacterial and cell biology up to animals, and even trees. For example,

- in cells, long microspikes or *filopodia*, can be produced by actin filaments deforming the cell membrane. However, the stress of the membrane exceeds the buckling limit of the slender filaments. One physical model shows that that the filopodia can resist collapse with as few as two actin filaments, if the straight filaments deform into a helix.[4]
- In animals, gecko feet have evolved a dry, non-chemical and reusable adhesive that adheres to vertical walls with a holding force that exceeds the breaking limit of their limbs. Therefore, it is equally remarkable is that the gecko has evolved a way to unstick its foot with negligible force.[5] Recently several labs have been developing dry adhesives based on the structure of gecko feet.[6] This is one application of the field of biomimicry, where the study of living systems has been used to uncover many novel strategies for the design of materials and systems.

It is also important to recognize that the meaning of the term “soft matter” is heavily nuanced by Pierre-Gilles de Gennes, who described the field in his 1991 Nobel Prize in Physics address— titled *Soft Matter*.[7-9] His approaches to finding simple estimates of the behavior of complex materials (e.g. his scaling theories) enabled major progress to be made in the understanding of numerous soft materials and systems. His approaches and philosophies are followed and strongly influence the field to this day.[9,11]

In summary, the field of Soft Matter Research involves the development of fundamental understanding and application of the physical and dynamical properties of soft matter. The field is interdisciplinary and involves research that is at the interface of Physics, Chemistry, Biology and Materials Science, and engineering application, especially in Chemical, Mechanical and Biomedical Engineering.

The range of application of the principles of soft matter is so broad, that a core focus and expertise at UofL in Soft Matter would be of great value in helping much of the UofL community (especially, the Sciences in A&S, Engineering, and Health Sciences) identify and use relevant soft matter principles in furthering many of its research activities. In the US as a whole, Soft Matter Research is receiving major funding. Of the 23 current National Science Foundation Material Research Science & Engineering Centers (MRSEC) at least 9 (NYU, U. Chicago, Harvard, MIT, Brandeis, U. Colorado, UPenn, UMass Amherst, Research Triangle: Duke/UNC/NCState) predominately focus on Soft Matter Research, and several other MRSECs have at least 1/3 of their activities focused on Soft Matter Research.[10] Soft Matter Research is rapidly and increasingly being recognized as a major emerging area of national research priority.

With at least 16 UofL working on various aspects of soft matter research (and many others yet to be identified) we are well positioned to develop a unified interdisciplinary focus in this research area. The development of a unified vision and increased collaborative funding will support longer range efforts to secure National Center Funding (e.g. a Materials Research & Engineering Center[2,10] or “MRSEC” from National Science Foundation.)

In order to maintain and enhance the reputation of its graduate programs and its research enterprise, it is important for UofL to continue to restructure its research focus and themes. The initiation of a cross disciplinary Soft Matter Research Program at UofL is just such a program that can enhance UofL’s research reputation. In fact, given the rapid emergence, recognition and funding for soft matter research at leading US institutions, it is critical that UofL initiates this program as soon as possible.

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