Carbon Nanotubes and Graphene: from Fluid Phases to Multifunctional Materials

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Nanoscale carbon includes Carbon Nanotubes (CNTs) as well as graphene, i.e., graphite in its single layered form. Nanoscale carbon has remarkable electrical, thermal, and mechanical properties, more so than previously known polymer molecules or colloidal particles. Realizing these properties in applications requires understanding and controlling the behavior of fluid phases. Biological and environmental applications are likely to require dilute phases of nano-carbon; material processing, e.g., production of coatings and fibers, will require more concentrated phases. Yet, “nano-carbon fluid” is almost an oxymoron because dispersing or dissolving CNTs and graphene into fluid phases is exceedingly difficult.

In this lecture, I will discuss how CNTs as well as graphene can and should be viewed as hybrids between polymer molecules and colloidal particles. Even at low concentrations (few parts per million), CNTs form complex fluid phases with intriguing properties. In crowded environments (e.g., gels), CNTs reptate like stiff polymers; surprisingly, the small bending flexibility of CNTs strongly enhances their motion: The rotational diffusion constant is proportional to the filament-bending compliance and is independent of the network pore size. In strong acids, CNTs as well as graphene dissolve spontaneously. At low concentration, these fluids can be used for making transparent, conducting films and coatings, as well as highly porous three-dimensional structures. At sufficiently high concentrations, CNTs and graphene both form liquid crystals that can be spun into well-aligned, macroscopic fibers. High quality bulk-grown CNTs can be processed by high-throughput wet spinning to yield high-performance multi-functional CNT fibers that combine the specific strength, stiffness, and thermal conductivity of carbon fibers with the specific electrical conductivity of metals. These scalable CNT fibers are positioned for high-value applications, such as aerospace electronics and field emission, and can evolve into engineered materials with broad long-term impact, from consumer electronics to long-range power transmission.