Mechanisms of NanoScale Self-Assembly

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As the 21st Century unfolds, chemistry-based, bottom-up approaches to the creation of materials with exactly specified atomic and molecular infrastructures have become more-and-more feasible and the top-down approach, which has served us so well, appears to be approaching some fundamental limits. The aim has been to access the promise that such new approaches hold for the formation of new materials with advanced function *eg* highly improved tensile strengths and/or novel electronic and magnetic properties, intelligent nanoscale machines for medical applications etc. As these new approaches to research in materials science have shifted more-and-more towards this more intrinsic chemical perspective, the field has acquired a new name, Nanoscience & Nanotechnology (N&N). It is of course not new as biology has done it this way since the first organisms appeared as all living systems are created atom-by-atom, molecule-by-molecule on the basis of a chemically coded recipe stored in DNA.

At the same time that these new approaches were developing, a totally unexpected new form of pure carbon, a family of cage molecules with fascinating properties was discovered - the Fullerenes (Buckyballs) together with their elongated cousins the Nanotube (or Buckytube). These nanoscale molecules and related structures have properties that should be able to fulfill some of the exciting promise of 21st Century Materials Science and Technology. The structures, which have also become the iconic images of N&N, are now the subject of intense study as they promise to play key roles in almost every possible area of future technology, from medicine and molecular electronics to civil engineering. In addition to carbon-based structures, the nanoscale behaviour of numerous other related materials is being explored with similarly exciting prospects. Ingenious strategies for the creation of molecules with complex, exactly-specified, structures and function are being developed – basically molecules that “do something” are now being made. As an example the drug industry has so far focused on the production of “relatively” simple molecules with exactly specified rigid structures but a plethora of complex molecules from electric motor enzymes and pulsing molecular machines abound within the body. These molecules are now highlighting incredibly exciting new directions for molecular biological research and challenging new perspectives for pharmaceutical research and development.

In fact, the cross-disciplinary field of N&N has resulted from a deep understanding and expert application of the fundamental chemical principles that underlie condensed matter physics, molecular biology and materials engineering. Indeed N&N may be considered *“Frontier Chemistry of the 21st Century”*. However, the mechanisms whereby various types of nanostructures assemble are still poorly understood. Over the last decade or so, we have examined a wide range of methods for nanostructure formation and from these studies important new insights have been gained. We have focused particular attention on the factors governing the creation of materials with intrinsically 1- and 2-D nanoscale infrastructures. Although some improvement in materials behaviour has already been achieved, it is unlikely that the technological paradigm shifts that N&N promise will be forthcoming until key fundamental mechanistic issues can be resolved and we have significantly improved fine control over bottom-up (chemical) self-assembly.