EDITORIAL

Clusters

Clusters are an important state of matter, consisting of aggregates of atoms and molecules that are small enough not to have the same properties as the bulk liquid or solid. Quantum states in clusters are size-dependent, leading to new electronic, optical, and magnetic properties. Clusters offer attractive possibilities for innovative technological applications in ever smaller devices, and the ability to "tune" properties, especially in semiconductors, may produce novel electronic and magnetic capabilities.

Exceptional progress is being made in synthesis, analysis, and theory in cluster research. In a special section in this issue of *Science*, five Articles cover current views of some of the most important and active areas of cluster science. The work is all fundamental but offers clear possibilities for practical applications. There is also a related Report and News coverage.

Semiconductors are one of the most active areas of cluster research. Many of their properties are very dependent on size; for example, optical transitions can be tuned simply by changing the size of the clusters. Alivisatos (p. 933) describes current research on semiconductor clusters consisting of hundreds to thousands of atoms—"quantum dots." These dots can be joined together in complex assemblies. Because of the highly specific interactions that take place between them, a "periodic table" of quantum dots is envisioned. Such coupled quantum dots have potential applications in electronic devices.

A News story by Service (p. 920) looks at possibilities for using the unique properties of nanoclusters in applications now or in the near future. The story focuses on applications that use the tunability of clusters, in quantum dot lasers, for example.

The magnetic properties of clusters are of fundamental interest and also offer promise for magnetic information storage. Shi *et al.* (p. 937) describe recent developments in the study of magnetic clusters, both isolated and embedded in a host material. Such clusters can behave like paramagnets with a very large net moment—superparamagnets. Superparamagnetic particles can be embedded in a metal and show dramatic field changes in electrical conduction. Ion implantation has generated ferromagnetic clusters embedded in a semiconductor host, which can be switched individually.

The constituents of clusters can be arranged in many different ways: Their multidimensional potential energy surfaces have many minima. Finding the global minimum can be a daunting task, to say nothing of characterizing the transition states that connect these minima. Wales (p. 925) describes the fundamental role of the potential energy surface in the understanding of the structure, thermodynamics, and dynamics of clusters. In a Report accompanying the special section, Ball *et al.* (p. 963) analyze Ar_{19} and $(KCl)_{32}$ clusters and illustrate how potential energy surface topography (the sequences of minima and saddles) governs the tendency of a system to form either amorphous or regular structures.

Water is essential to life and to a great number of chemical processes. Hydrogen bonding, the source of many of water's most interesting properties, requires at least two water molecules. Far-infrared laser vibration-rotation tunneling experiments on supersonically cooled small clusters allow characterization of geometric structures and low-energy tunneling pathways for rearrangement of the hydrogen bond networks. Liu *et al.* (p. 929) describe how these and other recent experiments on water clusters give insight into fundamental properties of water.

Simple aggregates of carbon atoms, especially C_{60}, are remarkably stable. Determination of their actual physical and electronic structures is a formidable task because of the large number of electrons and the many possible isomeric arrangements involved. Scuseria (p. 942) reviews the status of the field, including recent advances and current challenges in ab initio algorithms.

Recent progress in the study of atomic nuclei has shown that the atomic nucleus can be thought of as a cluster of subatomic constituents. Hall (p. 922) describes some remarkable progress in nuclear structure models in another News story.

The fundamental science involved in understanding clusters has great intellectual and practical value. In the interplay between important basic and applied problems, we see how critical it is to support both kinds of high-quality work. We must take care, however, not to ask too soon for the final product. Applications often become clear only after the fundamental work is done.

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