New Frontiers in Nanocarbons

by R. Bruce Weisman

Carbon is an extraordinary element. Its ability to covalently bond with different orbital hybridizations leads to a uniquely rich array of molecular structures that form the vast subject of organic chemistry. Approximately 20 million organic compounds containing carbon and other elements have been characterized, and it is estimated that than more than 90% of all recognized chemical compounds include carbon. By contrast, for millennia only two known substances were composed exclusively of carbon atoms: the elemental allotropes graphite and diamond. This situation changed dramatically in 1985 with the discovery of a new molecular allotrope, the soccer-ball shaped cage molecule C_{60}, also known as Buckminsterfullerene.

The discovery of C_{60} marked the dawn of carbon nanostructure research. In this field the focus is on all-carbon materials whose properties are determined by their specific covalent bonding geometries and the resulting well defined nanoscale structures. Activity in nanocarbon research grew explosively after the 1991 report of a method for making bulk quantities of fullerenes, and two years later a Fullerenes Group was formed within The Electrochemical Society to serve this new research community.

With dimensions of approximately 1 nm, C_{60} and related larger fullerenes such as C_{70}, C_{76}, C_{84}, etc. are studied using the experimental methods and concepts of chemistry. The scientific literature currently contains approximately 28,000 papers dealing with fullerenes. A second category of carbon nanostructure emerged in the early 1990s: nanotubes. Like fullerenes, these ordered cage structures are composed entirely of 5- and 6-membered covalently bonded carbon rings, but nanotubes are highly elongated and contain 5-membered rings only at their caps. Carbon nanotubes also exist in far more structural varieties than fullerenes. With their large aspect ratios and crystalline order along the tube axis, nanotubes must be studied from an interdisciplinary viewpoint that combines concepts from chemistry and condensed matter physics. Carbon nanotubes display remarkable properties that have attracted great interest among basic and applied researchers working in chemistry, physics, materials science, chemical engineering, electrical engineering, and biomedicine. More than 85,000 papers have been published to date on carbon nanotubes.

In 2004, a technique was demonstrated for removing and studying single atomic layers of carbon from graphite. These graphene sheets represent a third category of carbon nanostructures, with particularly unusual electrical properties arising from the semi-metallic pi-electron band structure. As is true for nanotubes, the network of covalent carbon–carbon bonds linking the entire structure also gives graphene very high strength and suggests novel mechanical applications. Graphene may be prepared as single-layer, double-layer, or multi-layer sheets through graphite exfoliation or through epitaxial growth on a variety of substrates, and narrow strips called graphene nanoribbons are of additional interest. The scientific literature already lists 27,000 papers on graphene.

As chemically-related nanocarbon research has expanded over the past 20 years to include structures that are essentially zero-dimensional (fullerenes), one-dimensional (nanotubes), and two-dimensional (graphene), the focus and size of the Fullerenes Group has grown accordingly. In 2000, the Group became a full Division of the ECS, and its name was expanded to Fullerenes, Nanotubes, and Carbon Nanostructures (abbreviated FNCN). It will soon be simplified to the "Nanocarbons Division."

Members of the FNCN Division conduct much of the world's leading basic and applied nanocarbon research. The three articles in this issue highlight a small sampling of this activity. One article summarizes several novel projects involving fullerenes, the first carbon nanostructure. It describes chemical synthesis of chiral fullerenes, supramolecular structures suitable as fullerene hosts, the use of fullerenes for studying molecular wires, and fullerene derivatives designed for biomedical applications. A second contribution focuses on possible electronic device applications of different nanocarbons and discusses the relation of their special physical properties to opportunities in this high value area. The third article focuses on a nanocarbon different from those mentioned above: carbon "onions," which can be viewed as multi-shell fullerene structures. Carbon onions display very unusual electrochemical properties that suggest a promising application as electrodes in micro-supercapacitors. The wide range of exciting topics described in these articles reflects the scope, quality, and vitality of current nanocarbon research.

About the Guest Editor

R. Bruce Weisman is a Professor of Chemistry at Rice University, with appointments in the Richard E. Smalley Institute for Nanoscale Science and Technology, the Rice Quantum Institute, and the Institute of Biosciences and Bioengineering. He is also the founder and president of Applied NanoFluorescence, LLC. Weisman's current research focuses on basic and applied studies of carbon nanotubes. Weisman has held an Alfred P. Sloan research fellowship and is an elected Fellow of the American Physical Society and Fellow of The Electrochemical Society. He is a former Co-Editor of the journal *Applied Physics A* and currently serves as Chair of the ECS Fullerenes, Nanotubes & Carbon Nanostructures Division.