All Worked Up About Buckyballs

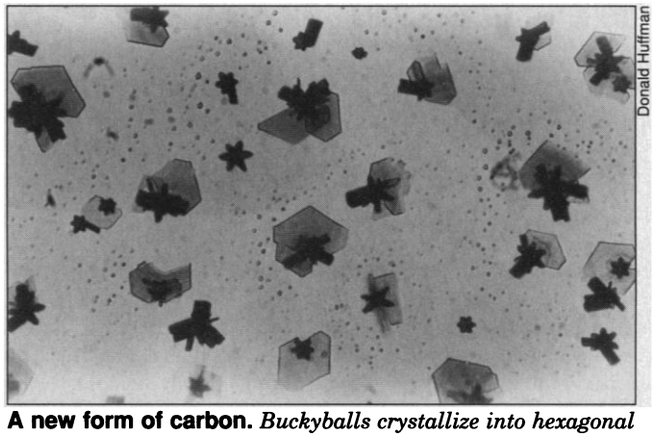
A breakthrough in the synthesis of an exotic carbon molecule has the chemistry community bubbling like a test tube over a hot Bunsen burner. "Things have just gone nova on us," said Richard Smalley at Rice University in Houston. "Most of the chemists in the department are working on this." At the University of Arizona in Tucson, Donald Huffman reported that "all my colleagues in the chemistry department" have dropped what they were doing to perform experiments on the new material. And at the University of California, Los Angeles, François Diederich said, "I haven't slept too much in the past couple of weeks."

The object of all the excitement is the spherical molecule C_{60}, known as "soccerene" or "buckminsterfullerene" or "buckyball" because of its shape—the 60 carbon atoms in the molecule are arranged at the vertices of a truncated icosahedron, a soccer-ball form popularized by Buckminster Fuller for use in geodesic domes. In the 27 September issue of *Nature*, Huffman and Lowell Lamb at Arizona and Wolfgang Krätschmer and Konstantin Fostiropoulos at the Max Planck Institute for Nuclear Physics in Heidelberg announced they had developed a way to synthesize relatively large quantities of C_{60} in a solid form. Although Smalley and co-workers discovered buckyballs in 1985, until recently no one had been able to make enough of them to study their chemical properties, which were suspected to be unusual. Now, suddenly and unexpectedly, chemists have a whole new area of exploration opening up in front of them. "There's hardly any area of chemistry this doesn't touch," Smalley says. "To a chemist it's like Christmas day. There are all these goodies."

Researchers expect those goodies will include a number of potential commercial applications. For instance, because C_{60} is thought to be very stable and slow to react with other substances, it should make an excellent lubricant. Some scientists have predicted the substance will make a good catalyst. And if organic chemists can attach hydrocarbon chains to the buckyballs, they may be able to synthesize organic compounds with new and valuable chemical properties.

The synthesis technique discovered by Huffman, Krätschmer, and co-workers is amazingly simple—simple enough to be done in almost any university chemistry department and even in some well-equipped high school labs, Huffman says. A graphite electrode is put in a vacuum chamber filled with helium gas at about one-eighth of normal atmospheric pressure. When a high electric current is passed through the electrode, the graphite slowly vaporizes, producing soot that settles on surfaces inside the chamber. This soot is then collected and stirred into benzene, which dissolves the buckyballs but not the other carbon fragments in the soot. After the undissolved matter is separated out, the remaining liquid is dried. The remaining solid is almost 100% C_{60} and C_{70}, a slightly elongated version of C_{60} that looks more like a rugby ball than a soccer ball. The C_{70} impurity apparently constitutes from 10 to 50% of the solid, depending on preparation.

What makes this new technique such a major advance is that, with an improvement introduced by Smalley, it's now possible to make up to 1 gram of C_{60} a day, several orders of magnitude more than was possible with the previous technique. With that method, scientists fired a laser at a graphite target, vaporizing part of its surface, and then swept the resulting gas of carbon atoms and clusters away in a stream of helium. To isolate the small portion of C_{60} molecules in the gas, they had to ionize the molecules and accelerate them in an ion beam. The yield in buckyballs was tiny and fast-moving, thus difficult to analyze. Indeed, until recently there was only indirect evidence that the atoms in a C_{60} molecule are actually arranged in the hypothesized soccer-ball shape.



A new form of carbon. *Buckyballs crystallize into hexagonal plates, which in this photo are about 10 micrometers across.*

That began to change last year when Huffman and Krätschmer discovered their method for producing the C_{60}-rich soot. They still, however, couldn't separate out the buckyballs, which make up less than 5% of the soot. Meanwhile, Donald Bethune and Gerard Meijer at IBM's Almaden Research Center in San Jose, California, came up with a method for depositing buckyballs onto a surface, forming a thin film of C_{60}. These feats allowed both groups to produce enough C_{60} in one place to identify the structure of the buckyballs with almost complete certainty.

But the amounts of pure C_{60} produced were still relatively small until this spring when Huffman and Krätschmer learned how to isolate and purify C_{60} with benzene. Only then was it possible to bring all of chemistry's analytical and synthetic techniques to bear on buckyballs. At this point, the research shifted into high gear.

In Smalley's department at Rice, for example, 17 researchers—about half the department—are collaborating on the C_{60} work. Everyone wants to try out his own specialty, Smalley says. Among their discoveries is the finding that it's possible to add one or two electrons to the C_{60} molecule and take them off again without affecting the molecule. This could, Smalley says, lead to a "whole new class of batteries." In another experiment, the Rice chemists attached 36 hydrogen atoms to the outside of the buckyball. This success implies, Smalley says, that it should be possible to attach chains of carbon atoms to the C_{60}. "It's behaving very much like you would expect from an aromatic molecule [a molecule containing a six-carbon benzene ring]," Smalley says.

Diederich said last week that he knew of six different groups racing to get papers on buckyballs into print, and the journals seem eager. When he and his colleagues submitted a manuscript detailing their latest results to the *Journal of Physical Chemistry*, it was accepted by fax the next day.

The excitement may seem exclusively intellectual, but it isn't. Since the discovery of an easy way to make C_{60} could have tremendous commercial potential, Huffman and Krätschmer filed a patent application on the process even before publishing their paper. "We're already working on how to scale it up to factory levels," Huffman says. Soon researchers and businessmen the world over may be playing this newest science sport: buckyball.

■ ROBERT POOL