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# Fullerene science—a most international endeavor

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Science in general and chemistry in particular are international cultural activities crossing international boundaries arguably more effectively than almost any other areas of human endeavor. Perhaps the discovery $C_{60}$ buckminsterfullerene and the birth of associated research fields are archetypal examples of this international aspect of science. Fullerene science and technology was born of a wide range of interdisciplinary initiatives and with many different facets. The discovery was made during a joint experimental program between the Rice University Cluster Research Group (Heath, Liu, O'Brien, Curl, and Smalley) in Texas (USA) and me at the University of Sussex in the U.K.[1] Smalley and his group at Rice had developed an ingenious technique in a major offensive on cluster science—they had created the LVSCBTOFMS! (the Laser Vapourisation Supersonic Cluster Beam Time of Flight Mass Spectrometer) whose *raison d'être* was destined to be the discovery that $C_{60}$ buckminsterfullerene can form spontaneously.

The earlier radio astronomy studies, which were the seed for the discovery experiment itself, were actually a spin-off from an earlier organic chemistry synthesis/spectroscopy program in our group at Sussex in the UK (Alexander, Kirby, Kroto, and Walton) on the molecular dynamics of carbon chain molecules. These studies led to the radioastronomy search for the chains in the interstellar medium with the Canadian National Research Council spectroscopists and astronomers (Oka, Avery, Broten, and Macleod).

Then it was "discovered" that the molecule had already been "discovered" before in the imaginative mind of Japanese scientist Eiji Osawa in 1970, who discussed the molecule further in a book called *Aromaticity* with Yoshida the following year. Then it was found that Russian scientists (Bochvar, Gal'pern, and Stankevich) had even published a Hückel calculation in 1972. In the USA, Davidson in 1980 had also studied the Hückel calculation as had Haymet at about the same time as the experimental discovery was made. It was then discovered that Jones, under the pseudonym of "Daedalus," had conceived of Giant Fullerenes; this idea had been stimulated by D'arcy Thompsons' famous book *On Growth and Form*. Before 1985, Birch, in Australia, had patented his so-called "Technigas" Generator, which almost certainly produced some $C_{60}$ and Tc encapsulated $C_{60}$ species. Oddly enough I found out about this soon after the publication of our paper in *Nature* in 1985, when an astute scientific advisor to Amersham International (Alan Peacegood) contacted me to enquire about my thoughts on whether the $C_{60}$ discovery might have any relevance to the medical technique. My thoughts at the time were that $C_{60}$ was probably involved but that the main vector was probably an aerosol of concentric graphite shell particles (giant concentric fullerene-like cages) with Tc atoms somehow intercalated in them. I suspected that the particles would be similar to those that had been described by Iijima in 1980.

When the extraction of $C_{60}$ was finally achieved in 1990, it was carried out by the joint Heidelberg (Germany) and Tucson (U.S.) team (Krätschmer, Lamb, Fostiropoulos, and Huffman). The extraction was aided and encouraged by various theoretical studies, particularly that of the optical spectrum by Rosen and coworkers in Sweden. The long, tall cousins of $C_{60}$, the carbon nanotubes that offer the possibility of revolutionizing structural and electrical engineering, were discovered by Sumio Iijima in Japan.

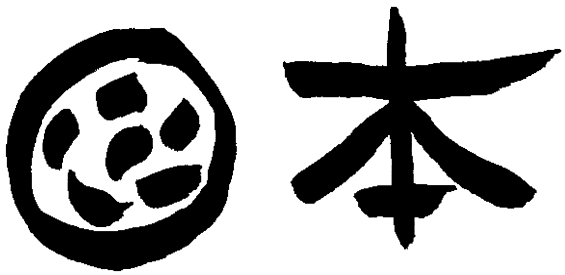

*Figure 1. In view of the fact that the $C_{60}$ molecule was first published in Japan, I have created new kanji for the country. The first symbol, which represents the molecule with spots indicating some of the pentagonal rings is a modification of the old round kanji symbol for the Sun. The loose translation is thus "The Land of the Rising Buckyball."*

Color Plate for this article is on page 274.

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One could go on and on in this international roll call, but before I finish I think we might highlight a little of what is known about the origins of the truncated icosahedral structure in art, architecture, and mathematics. Much is probably completely lost in the mists of antiquity; what remains is associated with the names of Archimedes (Greece), Leonardo da Vinci and Piero della Francesca (Italy), and Durer and Euler (Germany). Buckminster Fuller (USA) and Zung (Japan) of course designed the Canadian geodesic dome at EXPO, which gave rise to the name.

Today there are research groups all over the world, from India to France and from Mexico to Australia, actively researching all aspects of Fullerene and Nanotube science and technology. Fullerene-like particles and nanotubes form out of other sheet materials such as boron nitride and, as Tenne's group in Israel has shown, molybdenum sulphide. To bring all these musings to an appropriate focus and to pay some measure of homage to Eiji Osawa and the country of origin of the first article on $C_{60}$, I suggest that the Japanese flag be modified slightly as in Color Plate 1. I have also modified the "ancient" Chinese (Kanji) characters for Ni and Hon (slightly!) to point out something that was not known when the characters wree first created—that the sun is a bit like a soccer ball and sunspots are sometimes pentagonal (Figure 1). Thus, Japan should now be renamed as the "Land of the Rising Buckyball."

## REFERENCE

1 Kroto, H.W., Allaf, A.W., and Balm, S.P., $C_{60}$-buckminsterfullerene. *Chem. Rev.* 1991, **91,** 1213–1235