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LEONARDO THINKS

Opinion: : A Fuller Bridge

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The discovery of the sphere-like C_{60}buckminsterfullerene molecule, followed by the emergence of the whole new discipline of *fullerene chemistry*, provides an opportunity to lessen the separation of the "Two Cultures"of scientists and humanists described by C.P. Snow [1]. The drama of the discovery and the magnificent simplicity of the structure attract the attention not only of chemists and other scientists but of non-scientists as well. Both the story and the structure are rich in cultural implications.

During an experiment involving the use of laser beams to evaporate graphite in early September 1985, a group of scientists at Rice University in Houston, Texas- Harry Kroto, Rick Smalley, Bob Curl-and their students identified a set of conditions in which the C_{60} species could be produced in an incredibly high abundance relative to any other cluster. The extraordinary stability of the C_{60} molecule prompted the researchers to look for the structural reason for its formation. They first came to the conclusion that it must be a closed-cage structure. Having known this much, they should have recognized that its shape must be that of the truncated icosahedron, one of the 13 Archimedean polyhedra. Instead, the scientists were merely searching for a sphere-like structure composed mostly of same-size regular hexagons, based on the graphite sheets. They remembered, however, the structure of the U.S. pavilion at Montreal's Expo '67, which led them to the works of Buckminster Fuller. Working with models, they finally came to the conclusion that the structure of the molecule consists of 12 regular same-size pentagons and 20 regular same-size hexagons. The route to the discovery thus was connected in the researchers' minds to Fuller's name and they named the new molecule *buckminsterfullerene*[2]. This is a rather long name for a relatively simple compound. However, any systematic name would be even longer. It is also a respectable name for an important molecule, whereas other suggested names- such as footballene, soccerene, buckyball and the like-sounded too playful (the official soccer ball consists of the same number and form of patches as the truncated icosahedron).

Buckminsterfullerene is the third modification of carbon to be discovered (after graphite and diamond), and nature seems to have kept it secret for a long time. An avalanche of similar all-carbon molecules, all belonging to the fullerene family, and technically as many new modifications of carbon, have become known to exist. One of the most intriguing features of fullerene chemistry is that metal atoms can get inside the C_{60} ball-requiring that a new designation be devised to describe this mode of forming chemical associations. Thus, for example, the buckminsterfullerene molecule containing a lanthanum atom within it is designated as La@ C_{60}.

Another interesting feature of this discovery was that it resulted from a lucky crossing of two separate lines of research. In one, Kroto had been looking for molecules of interstellar space-for him, the laser-beam method of evaporating graphite served to mimic the interstellar conditions that are thought to lead to the formation of new species. In the other, Smalley had built a sophisticated apparatus in which loosely bound groups of atoms, called clusters, were formed and observed. The graphite- evaporation experiment combined their experience and interests and brought cluster physics and astrophysics together in a chemical exercise.

Their experiment, however, was not the first of its kind. About a year earlier, another group in a similar experiment had detected and published their research on the products of graphite evaporation by laser beam. Although the relative abundance of C_{60} was not so striking as in the Houston experiment, again, in hindsight, it should have been noticed. Not only was it not noticed by the researchers who produced the data, but the readers of the prestigious journal where the report had appeared did not notice it either [3].

When the report of the Houston group was published, it generated interest, but the real landslide of a new chemistry started when another team, led by Wolfgang Kratschmer of Heidelberg and Donald Huffman of Tucson, Arizona, found a simple way to produce the buckminsterfullerene in measurable quantities [4]. This enabled any chemist to experiment with the new substance.

The discovery of buckminsterfullerene, although serendipitous, was not made possible through luck alone but through hard work, training, experience and curiosity. As Louis Pasteur stated, "In the field of observation, chance only favors those minds which have been prepared" [5]. Curiously, several suggestions, unknown to the discoverers, had preceded the discovery, all pointing to the feasibility of the substance that today we call buckminsterfullerene. In 1970, Eiji Osawa ofJapan suggested the existence of C60 with a truncated icosahedral shape, based purely on symmetry considerations. In 1973, D.A. Bochvar and Elena G. Gal'pern of Moscow carried out some theoretical calculations that led them to postulate the great relative stability of a C_{60} molecule with a truncated icosahedral shape. Even before, in 1966, DavidJones of Britain mused in print about the possibility of graphite sheets curling up into hollow ball-like molecules.

Thus, there are many threads of the buckminsterfullerene story, and Fuller's involvement in the picture had more than symbolic significance. Fuller was not only the creator of geodesic domes but also an advocate of a physical geometry in which the dodecahedron and the icosahedron play an important role. His writings may be controversial but it is his influence, exerted over a broad range of disciplines, that not only survives him but also appears to provide fruitful stimuli in different fields. The physical importance of the icosahedron and the relevance of Fuller's teachings were stressed by the discoverers of virus structures, Donald Caspar and Aaron Klug, who stated in the early 1960s:

> The solution we have found ... was, in fact, inspired by the geometrical principles applied by Buckminster Fuller in the construction of geodesic domes.... The resemblance of the design of geodesic domes ... to icosahedral viruses had attracted our attention at the time of the poliovirus work... Fuller has pioneered in the development of a physically orientated geometry based on the principles of efficient design [6].

Alas, it seems that the influence on this important microbiological research has not spilled over to other fields.

The situation may be different with the buckminsterfullerene story. A whole new field is evolving, one that is new not only because of the unique shape of the C_{60} molecule but also because of the size range involved. Fullerenes appear not only as isolated molecules but also in a great variety of sheets, tubes and molecular wires. Potential applications range from superconductivity to anti-AIDS agents. Fullerene chemistry is becoming an important part of a new area of science, often called nanochemistry, which refers to a size-range based on a great, though finite, number of molecules.

This new chemistry has an added attraction in the accessible shape of the buckminsterfullerene molecule. The truncated icosahedron is not as common as the cube, yet it is not so complicated that it is difficult for non-scientists to understand and recognize. It is special enough to catch the eye and is shown in a conspicuously beautiful drawing by Leonardo da Vinci. When this shape is recognized outside the discipline of chemistry, it is pleasing to interested laypersons and recognizable as a children's jungle gym, a lamp or the soccerball itself.

Had the original discoverers known their geometry better, or had Euler's formula come to mind as soon as they started looking for the shape of a cage consisting of 60 carbon atoms, they might have had no reason to reach out to Buckminster Fuller. In that case the synergistic impact of their discovery would almost certainly have been much less significant. I am not praising the lack of being versed in geometry, however. On the contrary, one of the side benefits of this outstanding chemical discovery may be an enhanced interest in three-dimensional geometry and a strengthened commitment towards geometry education in our schools. This is but one aspect in which the smooth-rolling buckminsterfullerene molecules may facilitate closing the gap between our two cultures.

Endnotes

[1] . C.P. Snow, *Two Cultures and a Second Look* (Cambridge, U.K.: Cambridge Univ. Press, 1964). Snow's lecture, Two Cultures, was presented in 1950.

[2] H.W. Kroto,J.R. Heath, S.C. O'Brien, R.F. Curl, and R.E. Smalley, "C60: Buckminsterfullerene," Nature 318 (1985) pp. 162- 163.

[3] . E.A. Rohlfing, D.M. Cox, and A. Kaldor, "Production and Characterization of Supersonic Carbon Cluster Beams," *J. Chem. Phys*. 81 (1984) pp. 3322-3330..

[4] . W. Kratschmer, L.D. Lamb, K. Fostiropoulos, and D.R. Huffman, "Solid C_{60}: A New Form of Carbon," Nature 347 (1990) pp. 354-358.

[5] 5. "Dans les champs de l'observation, l'hasard ne favorise que les esprits prepares." Encyclopaedia Britannica, 11th Ed., Vol. 20 (1911), quoted here after A.L. Mackay, *A Dictionary of Scientific Quotations* (Bristol, U.K.: Adam Hilger, 1992).

[6] D.L. D. Caspar and A. Klug, "Physical Principles in the Construction of Regular Viruses," *Cold Springs Harbor Symposia on Quantitative Biology* 27 (1962) pp. 1-24.