25 years of C_{60}

The discovery of buckminsterfullerene has had a widespread impact throughout science.

Twenty-five years is a long time in nanotechnology. Cast your mind back to 1985: the scanning tunnelling microscope (STM) had been invented, but the atomic force microscope had not. It was 25 years since Richard Feynman had given his talk 'There's plenty of room at the bottom', but 15 years before the launch of the National Nanotechnology Initiative in the United States. It was five years after the Solidarity trade union had been formed in Poland, but six years before the collapse of the Soviet Union. It was also the year that C_{60} was discovered by Harry Kroto, Jim Heath, Sean O'Brien, Robert Curl and Rick Smalley — a feat that led to Curl, Kroto and Smalley sharing the Nobel Prize in Chemistry in 1996.

C_{60} was the first of a series of new carbon nanomaterials

It is fascinating to re-read the paper[1] reporting the discovery in *Nature*: the title is short and sweet ('C_{60}: Buckminsterfullerene'); the paper runs to less than two pages, there is a photograph of a football but no supplementary information; and in places the text is written in an informal style that is hard to imagine appearing in a journal today. "We are disturbed at the number of letters and syllables in the rather fanciful but highly appropriate name we have chosen in the title to refer to this C_{60} species," the authors conclude. "For such a unique and centrally important molecular structure, a more concise name would be useful. A number of alternatives come to mind (for example, ballene, spherene, soccerene, carbosoccer), but we prefer to let this issue of nomenclature be settled by consensus." The name buckminsterfullerene has stuck, as has the distinctly less poetic soubriquet, buckyball.

As Chris Toumey recounts[2] on page 693, Kroto and co-workers proposed that the C_{60} molecules had a truncated icosahedral structure (that is, the surface comprised 20 hexagons and 12 pentagons), but they were not able to confirm this in their 1985 paper. A group at Exxon disputed this structure, arguing that the molecules were planar, and conclusive evidence for the iconic icosahedral structure had to wait for the development of a new technique for producing greater numbers of the C_{60} molecules and STM images of these samples. (The Exxon group had actually seen evidence for clusters containing 60 carbon atoms in their mass spectra[3] but had not realized its significance.)

There are also less obvious differences between now and then, most notably the low-key approach to possible applications adopted by the authors of research papers. Today it is common for almost all papers in high-profile journals (including *Nature Nanotechnology*) to include at least one sentence in the abstract or first paragraph about possible applications in biosensing, imaging, drug delivery, nanoelectronics, quantum computing or some other area of advanced technology. Kroto and co-workers, however, begin by explaining that their work was motivated by a wish to understand more about the formation of long-chain carbon molecules in space. Potential applications (for example, as a superlubricant) are not mentioned until the penultimate paragraph. Of course, this is more than a matter of presentation: as Richard Jones has pointed out[4], over the past decade there has been a move away from testing theories and characterizing materials towards "making widgets or gizmos [that] did something or produced some functional effect", even if these widgets and gizmos are still quite far removed from real-world applications and products.

As it happens, C_{60} has not enjoyed a great deal of success in terms of applications, but that does not diminish the impact it has had in many areas of basic science. For example, the demonstration of wave-particle duality in C_{60} molecules[5] in 1999 was a landmark experiment in quantum mechanics, and the same group later went on to demonstrate wave-like behaviour in even larger fluorinated fullerene molecules[6] ($C_{60}F_{48}$). Other highlights from a long list of examples include the fabrication of a single-C_{60} transistor[7], the demonstration of superconductivity in a single-C_{60} transistor[8], unconventional superconductivity in caesium fulleride[9] (Cs_3C_{60}), and the observation of orientational ordering of C_{60} molecules on surfaces[10].

Potential applications are not mentioned until the penultimate paragraph

Furthermore, C_{60} was also the first of a series of new carbon nanomaterials that have fascinated the nanoscience and technology community over the past two decades — carbon nanotubes became the focus of intense research in the 1990s, and are still the subject of countless publications, and the rise of graphene shows no signs of stopping. Much of the interest in nanotubes and graphene is being driven by potential applications in the electronics industry[11,12]. Buckminsterfullerene may have been overtaken by its rival allotropes on this and other fronts, but it still retains the capacity to surprise — as the recent detection of C_{60} (and C_{70}) in space[13] for the first time confirms. And because the early work on C_{60} was motivated by problems in astrophysical chemistry, one can finally say that the story of this remarkable molecule has now turned full circle. ❐

References

1. Kroto, H., Heath, J. R., O'Brien, S. C., Curl, R. F. & Smalley, R. E. *Nature* **318,** 162–163 (1985).
2. Toumey, C. *Nature Nanotech.* **5,** 693–694 (2010).
3. Rohlfing, E. A., Cox, D. M. & Kaldor, A. *J. Chem. Phys.* **81,** 3322–3330 (1984).
4. Jones, R. A. L. www.softmachines.org/wordpress/?p=73 (2005).
5. Arndt, M. *et al. Nature* **401,** 680–682 (1999).
6. Hackermüller, L. *et al. Phys. Rev. Lett.* **91,** 090408 (2003).
7. Park, H. *et al. Nature* **407,** 57–60 (2002).
8. Winkelmann, C. B., Roch, N., Wernsdorfer, W., Bouchiat, V. & Balestro, F. *Nature Phys.* **5,** 876–879 (2009).
9. Takabayashi, Y. *et al. Science* **323,** 1585–1590 (2009).
10. Schull, G. & Berndt, R. *Phys. Rev. Lett.* **99,** 226105 (2007).
11. Rutherglen, C., Jain, A. & Burke, P. *Nature Nanotech.* **4,** 811–819 (2009).
12. Schwierz, F. *Nature Nanotech.* **5,** 487–496 (2010).
13. Cami, J., Bernard-Salas, J., Peeters, E. & Malek, S. E. *Science* **329,** 1180–1182 (2010).