ACS
Chemistry for Life®

The Discovery of Fullerenes

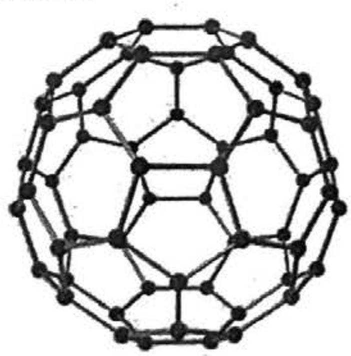
The discovery of new, all-carbon molecules known as fullerenes was the unexpected result of research into particles found in space. Scientists in different fields collaborated on the research that led to this discovery. No one set out to discover fullerenes—they were observed by scientists alert enough to realize they were seeing something new.

Today, fullerenes are at the heart of nanotechnology—the study of extremely small structures and devices on the atomic scale. This field provides many exciting new research possibilities for scientists.

Carbon Chemistry

Carbon, the basis of life, is one of the most common elements and one of the most studied. It comprises the whole discipline of organic chemistry.

A study of pure carbon would not seem all that exciting to most chemists. However, for British chemist Harry Kroto and the colleagues he enlisted in his research, a study into carbon molecules led to the discovery of a previously unknown, all-carbon molecule known today as a fullerene.



This is a Buckminsterfullerene or buckyball, a molecule made up of 60 carbon atoms arranged in the shape of a sphere. Fullerenes can also be shaped like cylinders, known as nanotubes.

Looking Up At the Stars

Harry Kroto, an organic chemist in the University of Sussex in the United Kingdom, became fascinated with various "peculiar" aspects of carbon chemistry. He also was interested in astrochemistry, the makeup of space and celestial bodies in the universe.

Kroto wanted to investigate the origins of the long linear carbon chain molecules he and Canadian scientists had discovered in interstellar space. He hypothesized that these unusual, long, flexible molecules had been created in the atmospheres of carbon-rich red giant stars, and he wanted to test this theory. But carbon, one of the most common elements, was already one of the most studied. At first, it was difficult for Kroto to find support for his research.

Collaboration

At a conference in 1984, Kroto met his friend Robert Curl, an American chemist who was working with colleague Richard Smalley at Rice University in Houston, Texas, to study atom clusters using a special instrument. Called an AP2 ("app-two"), the machine helps scientists study clusters of any element.

Kroto accompanied Curl back to his lab and examined the machine. He saw the possibility of putting carbon in it to explore his theory about carbon chain formation.

But Smalley had his own research to perform and didn't initially offer the AP2. However, a year later, Smalley agreed to let Kroto use the instrument for his experiments. Late in 1985, Kroto arrived in Houston to begin his experiment with Smalley and Curl.

The three scientists, aided by graduate students Sean O'Brien, James Heath and Yuan Liu, conducted the study. The students ran the AP2 with Kroto directing the experiments.

Within days, two significant results emerged from the experiments: First, the team found the long carbon chains in Kroto's hypothesis. Second, the scientists observed a previously unknown molecule of pure carbon.

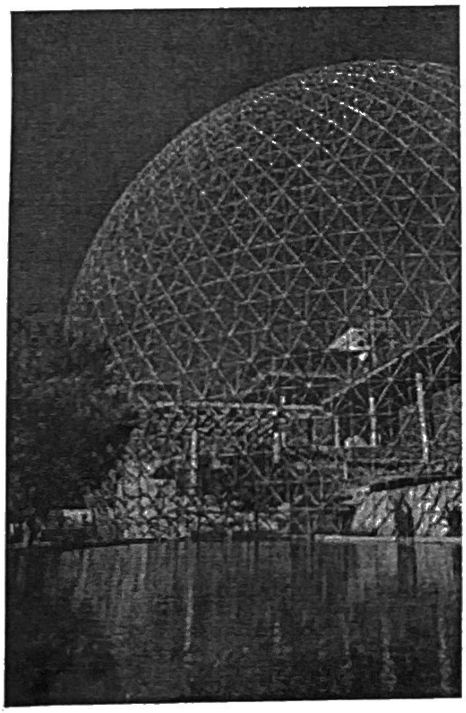
Unexpected Results

Using a mass spectrometer (a device used to determine the mass and molecular composition of molecules), the students noticed something remarkable: an odd indication of a molecule containing sixty carbon molecules. The molecule, C_{60}, formed very readily and exhibited extraordinary stability.

All known carbon-containing molecules, even benzene, a very stable ring of carbon atoms, have edges that terminate with other elements. But C_{60} was inert—it did not need hydrogen, or any other element, to tie up its bonds.

The scientists were stumped at first by the stable, 60-carbon molecule that did not react with other molecules, which suggested it had no dangling bonds: What was the structure of this new form of carbon?

The team considered two candidates for the structure of C_{60}: a flatlander model where carbon was stacked in hexagonal sheets, with the dangling bonds tied up in some fashion; or a spherical form where the hexagonal graphite sheet curled around and closed. A spherical structure would have no dangling bonds.



Buckminster Fuller's Montreal Biosphère at the 1967 World Exposition in Montreal.

At some point Buckminster Fuller, an American architect known for designing spherical structures called geodesic domes, was mentioned. Kroto recalled Fuller's architecture from a visit to the 1967 World Exposition in Montreal.

Kroto and Smalley thought hexagons made up the surface of Fuller's structures. Then Kroto remembered a dome he once made for his children. He thought it had both pentagonal and hexagonal faces, but he was unsure.

Eureka!

Smalley wondered if a shape composed of only hexagons could close. Perhaps the only way to find out was to build one.

Smalley tried first to generate the structure on his computer. Then he turned to paper, tape and scissors.

He began by cutting out and taping together hexagons, but when he attached them, he found that the hexagons would not close. Then he remembered Kroto's suggestion and began adding pentagons to the model.

Now no cheating was required. The model easily assumed the shape of a bowl. By interspersing pentagons among the hexagons, the result was a spherical structure with sixty vertices. Sixty, it turned out, was the only number of atoms that could form a nearly perfect sphere.

When Smalley tossed the paper model on a table in his office the next day, the team was ecstatic. Smalley had stumbled through trial-and-error on a mathematical truth Fuller employed in his domes, and which is exhibited in soccer balls: A spherical shape can be made using 12 pentagons and 20 hexagons.

Nobel Prize

At first, some scientists were skeptical of the team's discovery. With carbon being so well-studied, few imagined that new all-carbon structures would be possible. However, by the late 1980's, further proof of the existence of fullerenes made acceptance widespread.

In 1996, Curl, Kroto and Smalley received the Nobel Prize in Chemistry for their discovery of fullerenes. The presenter of the Nobel noted that the discovery of fullerenes has implications for all the natural sciences.

Nanotechnology

Research on fullerenes has resulted in the synthesis of more than a thousand new compounds. The discovery of fullerenes also led to research in carbon nanotubes, the cylindrical cousins of buckyballs. Carbon nanotubes can slide within an outer tube, suggesting possible uses in tiny motors and as ball bearings and lubricants.

Today, researchers are exploring nanotechnology in a search for applications in such areas as energy, body armor, antibiotics, superconductors, and optics.

More than 25 years after their discovery, fullerenes provide abundant research opportunities in pure chemistry, materials science, pharmaceutical chemistry and nanotechnology.