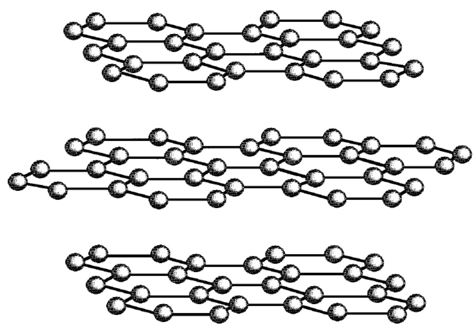
# Learn About ...

## BUCKYBALLS

The discovery of a new form of a pure element is a rather rare occurrence, especially for a common element. Therefore, reports of such discoveries generate an unusual amount of excitement among scientists. An example is the discovery in 1985 of a new allotropic form of elemental carbon. The two well-known forms of elemental carbon are graphite and diamond. Both of these contain extended arrays of carbon atoms. In the new form, the carbon atoms are arranged in relatively small clusters of atoms.

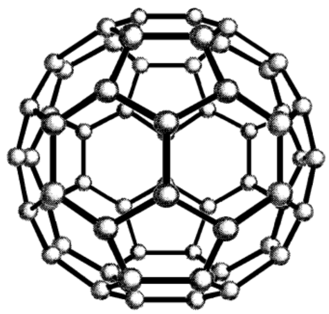


**Graphite**

In graphite, the carbon atoms are arranged in sheets with the bonds between the atoms forming hexagons, something like chicken wire. The sheets are only weakly bonded to each other, so they slide past one another, giving graphite a slippery feel and making it a good lubricant. Graphite is also used extensively in studies of the surface effects of energy in the form of light, heat, and electric current. When graphite is subjected to large bursts of energy of these sorts, portions of the top sheet of carbon atoms are ripped out. The ejected portions are studied to learn how the energy interacts with a solid surface.

In the early 1980s, Harold W. Kroto of the University of Sussex in England was using microwave spectroscopy to analyze the composition of carbon-rich stars. The analysis indicated that the atmosphere of these stars contained cyanopolyynes, which are composed of chains of alternating carbon and nitrogen atoms. Prof. Kroto wanted to study how these chains could be formed. He contacted Robert F. Curl and Richard E. Smalley at Rice University in Texas, because they had been using microwave spectroscopy to analyze clusters of metals formed in Prof. Smalley's lab. Prof. Smalley had an apparatus that could vaporize nearly any material into a plasma. In 1985, Kroto joined Curl and Smalley in Smalley's lab to study the products of carbon vaporization. They fired a high-energy laser beam at a graphite surface and used a stream of helium gas to carry the fragments into a mass spectrometer. The mass spectrometer revealed the masses of the fragments of graphite ejected from the surface. These fragments varied from several atoms up to about 190 atoms. The distribution of fragments depended on the pressure of helium in the carrier stream. As the pressure increased from several torr to about 1 atm, the distribution of fragments changed, and the fragment containing sixty carbon atoms became by far the dominant one. Because the laser pulse and graphite surface had not changed, they reasoned that the fragments that broke off were not changing, but instead that the way these fragments interacted on their way into the mass spectrometer changed. At higher helium pressures, the fragments would be jostled together more than at lower pressures. This jostling leads to the formation of the most stable form of small carbon atom cluster, namely $C_{60}$.

Kroto, Smalley, and Curl wondered how the atoms in this cluster are arranged to make it more stable than other clusters. They believed that its stability came from an arrangement in which all bonding capacity of the atoms is satisfied. In a small fragment of carbon-atom sheet ejected from a graphite surface, the atoms around the edge of the sheet would not be fully bonded. If, however, the sheet were to form into a ball so the edges would meet, the bonding capacity of all atoms would be satisfied. Prof. Smalley, building paper models in his kitchen, determined that the atoms are arranged in a soccer ball-like combination of 12 pentagons and 20 hexagons. Because this shape reminded him of the geodesic dome invented by Buckminster Fuller, he called the $C_{60}$ molecule "buckminsterfullerene."



**Buckminsterfullerene**

The amounts of buckminsterfullerene ("buckyballs," for short) prepared by laser were extremely small. The evidence for the structure would remain sketchy until $C_{60}$ could be prepared in larger quantities. Such a preparation was discovered in 1990. In this method, a water-cooled cylinder contains a sharp graphite rod touching a graphite disk. The cylinder is evacuated to a pressure of $1 \times 10^{-5}$ torr, and a current of 100 to 200 ampere is passed between the rod and the disk. This produces a soot that deposits on the walls of the cylinder. The soot is washed with toluene, producing a red-brown solution. When this solution is evaporated, it leaves a residue with a mass of about 10% of the original soot and containing more than 85% $C_{60}$. With this method, about 1 gram of $C_{60}$ can be produced in a day.

The appearance of a new form of carbon in a world that had only known graphite and diamond thrilled chemists and ignited a worldwide race to understand its traits. A whole new chemistry has developed in which fullerene molecules are manipulated to form compounds. Because the $C_{60}$ sphere is hollow, other atoms can be trapped within it. When a graphite sheet soaked in $LaCl_3$ solution is subjected to vaporization-condensation experiments, a substance with formula $LaC_{60}$ is formed. When other metal salts are used, the ball of carbon atoms can be shrunken with laser pulses to fit the metal ion within. In this way, $CsC_{48}$ and $KC_{44}$ were formed. Other experiments have produced new materials with $C_{60}$. For example, $C_{60}$ doped with potassium is a superconductor below 18 Kelvin. In the $C_{60}$ structure, other atoms have been substituted for the carbon atoms, producing derivatives such as $C_{59}N$ and $C_{57}B_3$. $C_{60}$ has also been used to produce three-dimensional polymers. The family of fullerenes has grown to include spherical molecules with various numbers of carbon atoms and cylindrical tubes of carbon atoms known as carbon nanotubes. Many researchers date the dawn of modern nanotechnology to the excitement ignited by the discovery of buckyballs.

In 1996, Harold Kroto, Richard Smalley, and Robert Curl shared the Nobel Prize in Chemistry for their discovery of buckminsterfullerene. For more information about this award, visit the Nobel Foundation webpage.