BUCKMINSTERFULLERENE: a new form of carbon

Carbon is an element of biological importance. It is on this element and one of its allies, hydrogen, that the whole branch of organic chemistry is based. Apart from its organic connections, pure carbon is of interest by itself. T Pradeep and S Balasubramanian describe the discovery of the new molecule of carbon, C_{60} which resulted from the joint efforts of chemical physicists and astronomers.

CHEMISTRY

MANY A discovery in science is accidental. Recent evidence to support this rather widely acknowledged thesis is the discovery of a new form of carbon called *buckminsterfullerene* or in chemical notation C_{60}. A group of scientists headed by Richard E Smalley of the Rice University, Houston, USA, hit upon this new molecule during their search for an understanding of the composition of interstellar dust.

Carbon is an element of biological importance. Apart from its organic connections, pure carbon is of interest by itself. Its two crystalline forms (allotropes), diamond and graphite have been very well studied and used in a variety of applications. Both these forms have widely divergent properties. For example, while diamond is a perfect insulator, graphite is an electrical conductor, diamond is the hardest substance known to mankind, but graphite is used as a lubricant - so soft that it finds ready application in writing pencils.

The discovery of the new molecule of carbon, C_{60} is a result of collaboration between chemical physicists and astronomers. It may seem a wierd combination at first sight: astronomers were for a long time puzzled over their observation of long chain molecules of carbon both in stars and in interstellar space and were trying to produce these molecules in the laboratory using sophisticated laser techniques. They worked first at Exxon Research Labs and later at Rice University. It was at the latter, that among te innumerable clusters, a hitherto unknown form of carbon was discovered. They observed that the mass spectrum of a vapour of graphite consists of a fairly intense feature at mass number 720, corresponding to a cluster of 60 carbon atoms. To their surprise, it was later found that the new feature was infact due to a very stable molecule, unlike the usually encountered clusters.

The system used to generate these molecules essentially used a laser beam to evaporate graphite. The sheets of graphite coming out were quenched by a pulse of helium gas and later analysed by mass spectrometry. This technique can reveal how much of a molecule of a particular weight is present in the sample. Though almost all clusters with even number of carbon atoms were present in the product, they found that under certain conditions of efficient quenching, the cluster containing 60 atoms alone was abundant.

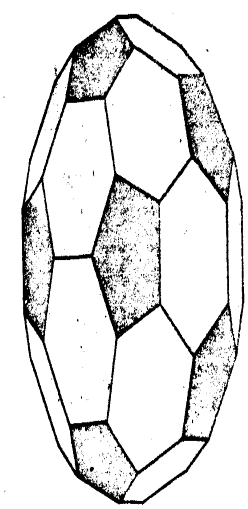
The remarkable stability of this new molecule as found out by its inertness to known reactants could not be explained by any structure other than that of the football, where every vertex is occupied by a carbon atom. This polyhedron has 32 faces, 12 of which are pentagons and 20 are hexagons. This would mean that all the carbon atoms are equivalent. That this was indeed so was proved by nuclear magnetic resonance (NMR) spectroscopy.

The structure of a modern football (soccer ball) which has 60 corners where carbons can sit is one of the many geodesic structures which Buckminster Fuller enunciated in the 1960's. These symmetric structures with which he constructed houses, domes etc are known for their remarkable structural stability. In the case of C_{60}, stabilisation results in the inertness of the molecule.

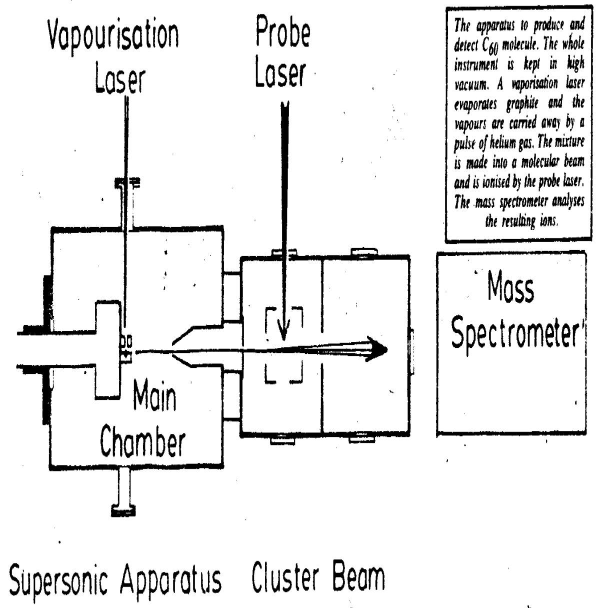
The cavity within the molecule is as large as 7 angstrom in diameter. A variety of foreign atoms and molecules can be "pushed inside" the void. The resulting material can have interesting properties. The first application that the discoverers themselves proposed, is lubrication. The present day solid lubricants mainly contain sheets of atoms, like graphite and molybdenum ulphide in which the foree can be "sheared off". With C_{60}, one can "roll off" the, forces. This molecule can be used in catalysis, as well as in organometallic chemistry. It can be used as a cavity for confining radioactive nuclei – molecular trap!

The discovery of this fascinating molecule would reveal more about soot, the black residue we find in our fireplace. Its formation has long been an enigma, particularly its sphericity. The near spherical structure of C_{60} may imply that it is the nucleus for the formation of soot.

The structural unit of the buckminsterfullerene is known to chemists for a long time. Called corannulene, it is an organic molecule which was first synthesised in 1966. The structure of buckminsterfullerene is a superposition of 12 corannulene molecules with each hexagon shared by three pentagons. In fact, the possibility of synthesising such a molecule by wrapping up of graphite sheets was speculated in 1966 itself.



The structure of buckminsterfullerene.



The apparatus to produce and detect C_{60} molecule. The whole instrument is kept in high vacuum. A vaporisation laser evaporates graphite and the vapours are carried away by a pulse of helium gas. The mixture is made into a molecular beam and is ionised by the probe laser. The mass spectrometer analyses the resulting ions.

Very recently, researchers from Germany have been able to make macroscopic quantities of this substance through a much simpler method of arcing graphite electrodes. The essential principle of quenching the sheets of graphite remains, however. After some processing of the resultant soot, one is able to get the footballene in sufficiently large quantities, which are needed to do other experiments.

The reverberations of this discovery is being felt in all disciplines. While astronomers try to explain their observations in the light of this new-found knowledge, organometallic chemists would like to study the cavity and the reactivity of this molecule. And material scientists are busy developing applications. Further experimentation on this molecule may perhaps answer many unresolved problems.