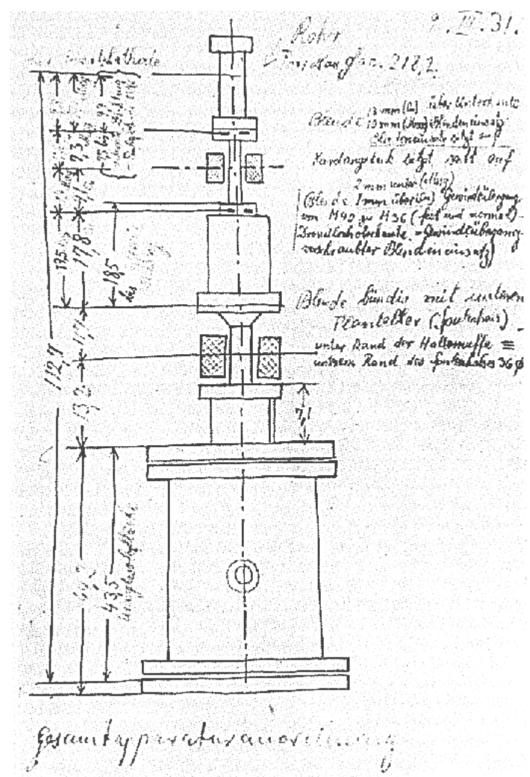
The Many Faces of Carbon

by Marilynn Johnson

Found in abundance in the universe, in the sun, in the stars, comets and in the atmosphere, carbon is the basic component of all organic matter. Carbon is found everywhere from the graphite in a pencil, to the soot in a chimney, to the diamonds in a jewelery box (4). Carbon is found in many different forms, or allotropes, such as diamond, graphite, coal, and charcoal. The properties and applications of carbon span an amazing breadth, and the possibilities for future applications of carbon are virtually limitless.

Most carbon is found in a form other than pure carbon: in a carbon allotrope or fullerene. An allotrope is “a structurally different form of an element” (3). For example, graphite, diamond, and Carbon 60 are allotropes of carbon. These allotropes are composed entirely of carbon but have different physical structures. A fullerene is any of the various cagelike, hollow molecules composed of hexagonal and pentagonal groups of atoms, and especially those formed from carbon (3). Diamond and graphite, known for centuries, have quite different properties. Diamond is a hard, colorless solid and graphite is a soft, black solid, but both consist entirely of carbon atoms. This makes them allotropes of carbon, and for a long time they were thought to be the only carbon allotropes with well-defined structures. In the 1980s another carbon allotrope was discovered in soot products when carbon-containing materials are burned with very little oxygen. The new allotrope consists of 60 carbon atoms and represents a new class of molecules (1).

Diamond is the hardest known substance (6). It is inert to chemical corrosion and can withstand compressive forces and radiation. It conducts heat better than any other material, has extremely high electrical resistance, and is transparent to visible light, x-rays, ultraviolet radiation, and much of the infrared spectrum. And, with respect to most of these features, diamond is superior to all other known materials (6). Diamond has the highest thermal conductivity of any solid at room temperature (4). It is the ideal optical material capable of transmitting light from the far infrared to the ultraviolet. Diamond has extremely high strength and rigidity, and the highest atom-number density of any material (4).



Diamonds are formed naturally in the earth’s mantle in regions of high temperature and pressure. Volcanic eruptions that originate from these regions bring diamonds to the earth’s crust in rocks known as kibberlites. These diamonds are then mined from the conduits of the volcanoes and from nearby glacial deposits in stream beds and beaches (6).

In 1990 the first artificially-produced diamond film was made possible (6). The artificially-produced diamonds are made in two stages. First, the researchers gradually deposit carbon gas onto a pre-existing diamond surface which forms a film of diamond. Then they cut the film into gemstones and expose the rocks to temperatures up to two thousand degrees Celsius and pressures of 50,000 to 70,000 times atomic pressure which produces exceptional hardness. Researchers say these crystals could be useful in tools for cutting and abrading (7).

Now there is another technique being developed known as Chemical Vapor Deposition. In this low-pressure technique, hot carbon-containing gases condense and react on a hard surface to form a thin coating of diamond (7). This technique would allow for artificially produced diamonds that are bigger and have less impurities and crystalline defects than those produced by the original method in a process that works one hundred times faster than the older method (7). It would also make artificially-produced diamonds affordable and accessible for use in science and industry.

A few diamond-based and diamond-coated products are already in use commercially, such as x-ray windows in electron microscopes, strong abrasion-resistant industrial tools, diaphragms for tweeters in stereo speakers, and diamond optical windows for spacecraft. The future applications possibilities include diamond substrates for semiconductors, high thermal conductivity and high electrical resistivity integrated diamond circuits, and polycrystallin diamond films on abrasion-resistant tools (7).

Graphite has been used since the 15th century, but today the applications of graphite have far surpassed use as a writing tool. Graphite is made of extremely strong fibers composed of series of stacked parallel layer sheets. When you write with a pencil, the marking is created by these sheets sliding off and settling onto the paper. Graphite is black and lustrous, optically opaque, unaffected by weathering, with a pronounced softness graded lower than talc. Its greasy friction-resistant properties allow for applications in lubricating oils and greases, dry-film lubricants, batteries, conductive coatings, electrical brushes, carbon additives and paints (4).

The Carbon 60 fullerene resembles a soccer ball with a carbon atom at each corner of each of the black pentagons (1). Each five-member ring of carbon atoms is surrounded by five six-member rings. This molecular structure of carbon pentagons and hexagons reminded its discoverers of a geodesic dome, a structure popularized years ago by the innovative American philosopher and engineer R. Buckminster Fuller. Therefore, the official name of the C60 allotrope if buckminsterfullerene. Chemists often call it simply a ‘buckyball’ (1).

C60 buckyballs belong to a larger molecular family of even-numbered carbon cages that is collectively called fullerenes (1). This molecule has been able to curl into a ball, perfectly tying up all dangling bonds (2). The truncated icosahedron arranges the maximum possible number of atoms uniformly on the surface of the sphere C60 “can be isolated from soot using a Soxhelt extraction followed by chromatography” (2). It holds possibilities in “antiviral activity, enzyme inhibition, DNA cleavage, photodynamic therapy, electron transfer” (3), “ball bearings, light-weight batteries, new lubricants, nanoscale electrical switches, new plastics, antitumor therapy for cancer patients and combustion science and astrophysics” (1).

There is an abundance of other forms of carbon allotropes and fullerenes besides Diamond, Graphite, and C60. All these materials are derived from organic precursors. The carbonization process is the step in which the organic precursor is turned in a material that is essentially all carbon. This generally involves a heating cycle in which the precursor is slowly heated in a reducing or inert environment. The organic material is decomposed into a carbon residue and volatile compounds diffuse out to the atmosphere. Pressure modifies the structure of the resulting carbon, changing its characteristics (4).

One such product of this is vitreous carbon. This non-crystalline structure was developed in the 1960s from polymers in a process of molding and carbonization. It has a structure that is closely related to that of a glassy material with high luster and glass-like fracture characteristics (hence the name vitreous which means glassy). Vitreous carbon has the form of an extensive and stable network of graphitic ribbons. It has high strength and high resistance to chemical attack, as well as extremely low helium permeability. It is used in vessels for chemical processing and analytic chemistry such as crucibles, beakers, boats, dishes, reaction tubes and lining for pressure vessels (4).

Molded graphite is a synthetic graphitic product made from petroleum coke and coal-tar manufactured by a compaction process from a mixture of carbon filler and organic binder which is subsequently carbonized and graphitized. Original applications included electrodes for electric-arc furnaces and movie projectors. Now molded graphite is found in almost every corner of the industrial world and forms the base of the traditional graphite industry (4).

Carbon fiber was first made from polymers in a process of carbonization and combustion by Thomas Edison when he was developing possibilities for filament for light bulbs. Although carbon fiber was scrapped as a light bulb filament, in 1950 large-scale production of carbon fiber began for use in cloth and felt made from carbonized rayon. These fibers were first developed for reinforcement of ablative components for rockets and missiles. Today, carbon fibers are low density, high strength, high modulus and are decreasing in cost. They are used in products spanning from racing cars to fishing poles, tennis rackets to sailboat spars, competition skis to airplane stabilizers (4).

Pyrolytic graphite is produced in a chemical vapor deposition process. Developed in the 1880's by carbon deposition to improve the strength of lamp filaments, pyrolytic graphite is comprised of methane and other gaseous hydrocarbons. Pyrolytic graphite is produced by a process based on a gaseous precursor instead of a solid or liquid. It is the only graphitic material that can be produced effectively as a coating. Since an increase in production after World War II, pyrolytic graphite is produced in bulk form mainly for use in coatings, deposited on substrates such as molded graphite, carbon fibers, or porous carbon-carbon structures as well as for extensive use in the coating of specialty molded pharites and in the processing of carbon-carbon components. Because of its non-reactive nature, pyrolytic graphite is also used as the material for the coating of nuclear fission particles that contain fission products as well as in heart valves and dental implants (4).

The radioactive decay of Carbon 14 provides a reliable way of dating materials that are up to 30,000 years old. This method of carbon dating is used extensively in archeology and paleontology for things such as to date wood from tombs or to determine the age of dead-sea scrolls and prehistoric animals and plants. This technique has also been used in the dating of trees caught in the glaciers allowing for mapping of glacial cycles of the past 30,000 years (4).

Carbon Nanotubes, a spin-off product of fullerene research were discovered in 1991 by S. Iijima. Nanotubes consist of graphitic layers wrapped into cylinders only a few nano-meters in diameter and up to a milli meter long. This means that the length-to-width aspect ratio is extremely high. The physical properties of carbon nanotubes are still being discovered and disputed in the scientific community. This is because nanotubes have a very broad range of electronic, thermal, and structural properties that change depending on the nanotube's diameter, length, and chirality, or twist (4).

Carbon can be formed into many different molecular structures. Other forms of carbon not yet mentioned include: diamond-like carbon, activated charcoal, carbon-carbon composites, coal, charcoal, hydrocarbons, gaseous hydrocarbons, lampblack, and carbon black. Carbon is found in virtually an infinite number of forms. It is found in the crystalline structures in real and artificial diamonds, which are useful in cutting and abrading because of their molecular density and are considered to be the most precious gemstone because of their luster and rarity. Carbon sheets that are layered in parallel comprise graphite, which is used for its lubricating qualities and softness. C60 buckyballs are the newest discovery and the third and final carbon allotrope. These hollow cages may one day have important medical and industrial applications. The many faces of carbon are everywhere in our daily lives, and through scientific and technological advances we are just beginning to tap into the many possibilities of carbon.

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