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Carbon Nano World: An Overview

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Abstract

Carbon is capable of forming many allotropes due to its valency. Well-known forms of carbon allotropes include diamond and graphite. In recent decades, many more nano-dimensional carbon allotropes have been discovered such as fullerene, graphene, nanotubes, nanotori etc. Synthesis, structures, physical properties as well as applications of these special nano-structured carbon allotropes are discussed here.
Keywords: C***arbon allotrope, Fullerene, Nanotubes, Nanotori.***

1. Introduction

Life is based on carbon; organic chemistry studies compounds in which carbon is a central element. The properties of carbon make it the backbone of the organic molecules which form living matter. It is a versatile element because it can form four covalent bonds and this unique property make it very special in the world of allotropy. Some allotropes are crystalline and others are amorphous in nature. Diamond is one of the best known crystalline allotropes of carbon, whose hardness and high dispersion of light make it useful for industrial applications and jewelry. Diamond is the hardest known natural mineral, which makes it an excellent abrasive and makes it hold polish and luster extremely well. Another interesting allotrope is graphite. Unlike diamond, graphite is an electrical conductor, and can be used, for instance, as the material in the electrodes of an electrical arc lamp. Carbon that does not have any crystalline structure is called amorphous carbon. Coal and soot are both informally called amorphous carbon.
The discovery of fullerenes [1-3] from laser vaporization of graphite has opened up a new wide area of research [2,4-7] in fundamental condensed matter physics, chemistry and material sciences confirming carbon as most versatile and essential element of nature. In chemistry it led to the opening up a new branch of organic chemistry, called fullerenoid chemistry as the discovery of benzene opened up benzenoid chemistry. Twenty-five years on from the discovery of, the outstanding properties and potential applications of the synthetic carbon allotropes such as fullerenes, nanotubes and graphene tremendously illustrate their unique scientific and technological importance. These nano carbon molecules are potentially useful in many applications e.g. in nanotechnology, electronics, optics and the other field of material science as well as architectural field.

1.1 Synthesis of carbon nano molecules

The first appearance of fullerene molecules in connection with an experiment i.e. graphite laser vapourization was proposed by Kroto, Heath, O'Brien, Curl and Smalley in the year of 1985 [1]. In the laser ablation process a pulsed laser vaporizes a graphite target in a high temperature reactor in an inert gas atmosphere. With time mordern techniques have been developed for the synthesis of nanotubes in sizeable quatities. Arc discharge is the most widely-used method of nanotube synthesis [8]. In this process the cabon contained in the negetive electrode undergoes sublimation because of the high discharge temperature. Chemical vapour deposition (CDV) is another interesting mehod and it was first reported in the year of 1959 [9] though it was not before 1993 that aligned carbon nanotubes arrays were synthesised in this metod [10]. In this process matal nano particles of cobalt, nickel, iron or their combination are used. Fulleren and carbon nanotubes are not necessarily products of high-tech laboratories. Often they are also produced by burning methane, ethelyne or benzene in ordinary flames at mundane places. They have been found inaturally in soot from both indoor and outdoor air. But these naturally occuring carbon nanotubes are very irregular in size. Nowadays efforts have focused on producing more uniform carbon nanotubes under controlled flame.

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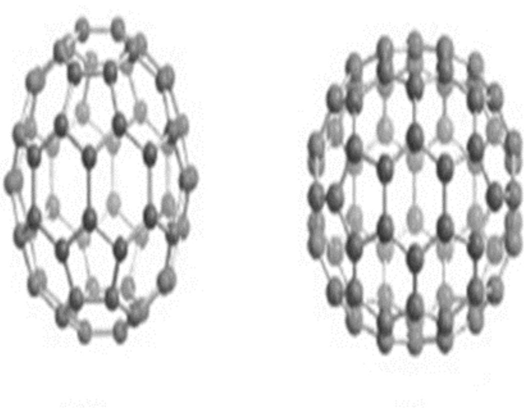
1.2 Different types of carbon nano molecules and their structures

Fullerenes (C_n) are closed carbon-cage molecules containing only pentagonal and hexagonal rings. But exception is there e.g. C_{20} which consists of twenty pentagonal rings. C_{20} fullerene is the smallest fullerene and have dodecahedron structure with I_h point group symmetry. It is very difficult to synthesize but Prinzbach et.al. has succeeded in the synthesis of C_{20} fullerene via a chemical method [11]. C_{60} molecule is the most popular fullerene as well as the the smallest fullerene without adjacent pentagons. It has icosahedron structure with I_h point group symmetry. The next smallest fullerene without adjacent pentagons was a D_{5h} isomer of C_{70} as showen in Fig. 1.



a b

Fig. 1 (a) The two most abundent produced in experiment

C_{60} (I_h) and (b) C_{70} (D_{5h})

Graphene which is basically a single layer of graphite is a very interesting allotrope of carbon. Graphene consists of a single layer of carbon atoms arranged in a hexagonal lattice as shown in Fig. 2. Andre and Kostya received the Nobel Prize in physics for their spectacular job i.e. isolation of graphene in the year of 2010. Its sp^2 hybridised carbon atoms are densely packed in a regular hexagonal pattern.

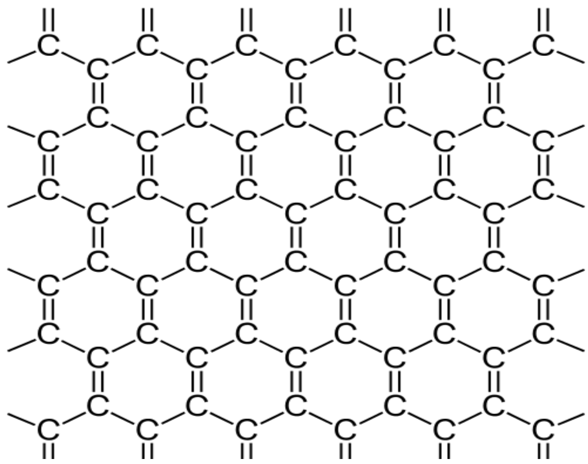


Fig. 2: structure of graphene sheet

Carbon nanotube, particularly single walled (SWNT) ones can be imagined to be formed by rolling a single layer graphite (i.e., graphene) sheet into a seamless cylinder and depending on mode of rolling up it can be arm chair, zigzag, and chiral. The warping of graphene sheet can be represented by a pair of indices (n , m). The integers, n and m , are the number of unit vectors along the two directions on the graphene sheet. If $m = 0$, the nanotube is zigzag (n , 0), if $n = m$, it is armchair (n , n) and if $n \neq m$ but none is zero, the nanotube is called chiral (n , m). Their structures are shown in Fig. 3.

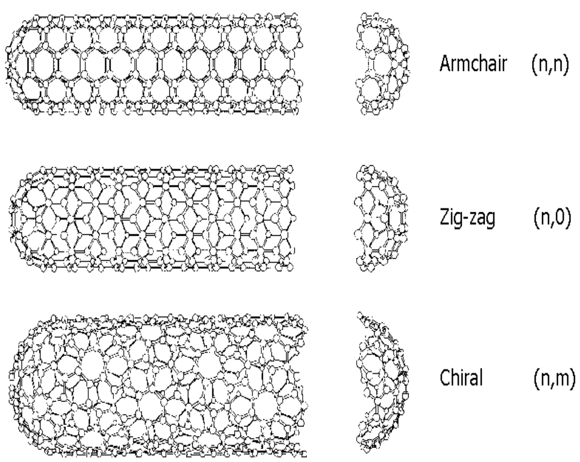


Fig. 3 Structures of different single walled carbon nanotubes

Multi- walled tanotubes (MWNT) consists of multiple rolled layers (concentric tubes) of graphite. There are two models which can be used to describe the structure of MWNT. One is Russian doll model, here it is assumed that graphite sheets are arranged in concentric cylinders. Another model is Parchment model. As per this model a single sheet of graphite is rolled in around itself. These two models are shown in Fig. 4.

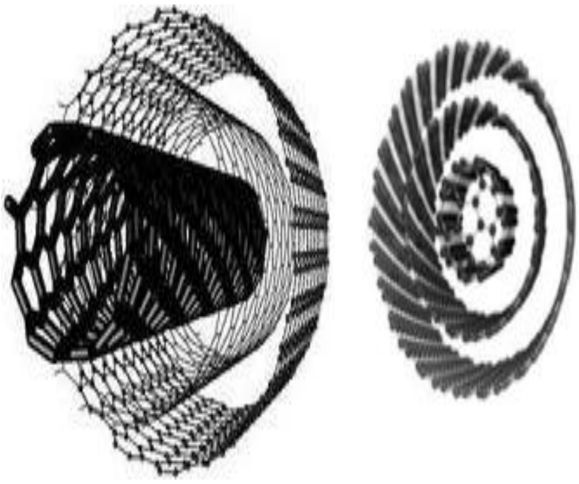


Fig. 4 Russian doll Parchment model for multi- walled nanotubes

1.3 Physical properties

Carbon nanotubes are a form of carbon, similar to graphite found in pencils. They are hollow cylindrical tubes and are 10,000 times smaller than human hair, but stronger than steel. They are also good conductors of electricity and heat, and have a very large surface area. The diameter carbon nanotube is of nanometer size though its length may vary up to 1µm. Carbon naotubes are very strong and stiff materials in terms tensile strength and elastic modulus respectively. Under excessive tensile strain, the tube will undergo plastic deformation. Carbon nanotubes are not nearly as strong under compression because of their hollow structure. Multi-walled nanotubes bear multiple concentric nanotubes which nested within one another. This typical structure exhibit a striking telescopic property. The inner nanotube core of this MWNT remains almost in frictionless condition thus can act as a linear or rotational bearing. The electronic structure of grapheme is very symmetric and unique. Thus nanotube exhibit an interesting electrical property. A (n, m) nanotube can function as a good or moderate semiconductor depending on the relation between m and n. All nanotubes are expected to be very good thermal conductors along the tube, showing the property called ballistic conduction but good insulator laterally to the tube axis. A SWNT has a thermal conductivity along its axis and across are $3500 Wm^{-1} K^{-1}$ and $1.52 Wm^{-1} K^{-1}$ at room temperature [12,13]. Crystallographic defects also affect the tube's thermal properties. Determining the toxicity of carbon nanotubes has been one of the big questions in nanotechnology. Some physical properties such as size, surface area, surface charge, agglomeration state as well as purity of the samples have great impact on the reactivity of the carbon nanotubes. Carbon naotubes can penetrate the cell membrane and causes harmful effect such as inflammatory and fibrotic reactions [14].carbon nanotubes can also enter human cells and accumulate in the cytoplasm, causing cell death [15].

1.4 Potential Applications

Recently studies have highlighted the prospect of using carbon nanotubes in several fields. Carbon nanotubes are successfully utilized in different fields e.g. biological specially biomedical field, material science, environmental science etc. They are used as an important component in manufacturing of different solar cells, microelectronic gadgets, transistors, batteries, supercapacitors, electrical wires and many more. It has been shown that carbon nanotubes exhibit strong adsorption affinities to a wide range of aromatic and aliphatic contaminants in water because of their large and hydrophobic surface areas. This property of nanotube make it as a promising material for water treatment.

2. Conclusion

As a conclusion we can say that nanotechnology is a very modern technology which is gift of revolutionary science. Not only carbon nano particles but different kinds of nano particles are synthesized. Different types of industrial materials with their suitable properties can be produced applying nanotechnology and thus fulfill our requirement. Nanotechnology can also be applied in different energy transformation also. Nano particles bring a tremendous change in medicinal science. Nanotechnology covers a lot of domains today and will cover a lot more in the near future.

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