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CARBON NANOTUBES - AN ENVIRONMENT FRIENDLY NANOTECHNOLOGY

Dr. Dipak K. Chandre[1*], Dr. Ravindra B. Kanawade[2], Dr. Ganesh B Shinde[3],

[1*]Assistant Professor, Department of Chemical Engineering, Sir Visvesvaraya Institute of Technology, Nashik, Maharashtra, India-422102
[2]Associate Professor, UPL, University of Sustainable Technology, Ankleshwar, Gujrat-393135
[3]Assistant Professor, Department of Chemical Engineering, Sir Visvesvaraya Institute of Technology, Nashik, Maharashtra, India-422102

[*]**Corresponding Author:** Dr. Dipak K. Chandre
[*]Assistant Professor, Department of Chemical Engineering, Sir Visvesvaraya Institute of Technology, Nashik, Maharashtra, India-422102

Abstract:
Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. They exhibit extraordinary strength and unique electrical properties and are efficient conductors of heat. Their final usage, however, may be limited by their potential toxicity.
Keyword: Carbon Nanotubes (CNT), Nanotechnology.

Introduction:
Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 28,000,000:1,[1] which is significantly larger than any other material. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. They exhibit extraordinary strength and unique electrical properties and are efficient conductors of heat. Their final usage, however, may be limited by their potential toxicity.
Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs. The ends of a nanotube might be capped with a hemisphere of the buck ball structure. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to several millimeters in length (as of 2008). Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).
The nature of the bonding of a nanotube is described by applied quantum chemistry, specifically, orbital hybridization. The chemical bonding of nanotubes is composed entirely of sp^2 bonds, similar to those of graphite. This bonding structure, which is stronger than the sp^3 bonds found in diamonds, provides the molecules with their unique strength. Nanotubes naturally align themselves into "ropes" held together by Van der Waals forces. Under high pressure, nanotubes can merge together, trading some sp^2 bonds for sp^3 bonds, giving the possibility of producing strong, unlimited-length wires through high-pressure nanotube linking.

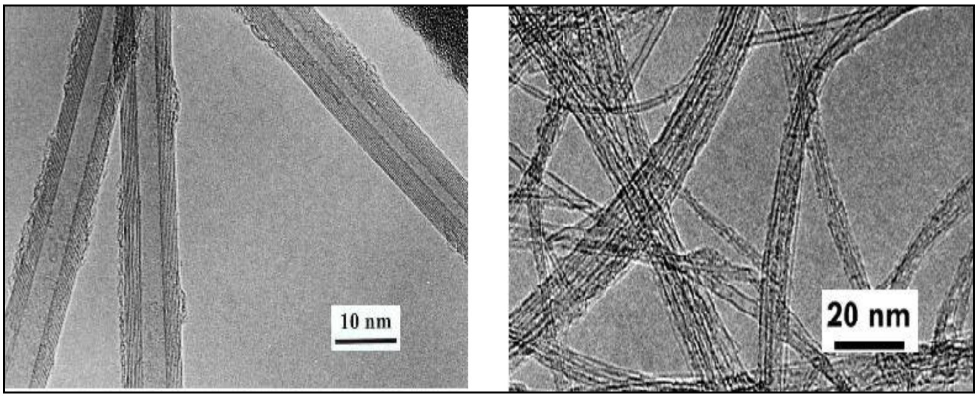

Figure 1: TEM image of MWNT and SWNT

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Structure of CNTs:

The bonding in carbon nanotubes is sp^2, with each atom joined to three neighbors, as in graphite.

The tubes can therefore be considered as rolled-up graphene sheets (graphene is an individual graphite layer). There are three distinct ways in which a graphene sheet can be rolled into a tube, as shown in the figure 1.

The first two of these, known as “armchair” (top) and “zigzag” (middle) have a high degree of symmetry. The terms "armchair" and "zigzag" refer to the arrangement of hexagons around the circumference. The third class of tube, which in practice is the most common, is known as chiral, meaning that it can exist in two mirror-related forms.

Types of carbon nanotubes:

1) **Single-walled:**

Most single-walled nanotubes (SWNT) have a diameter of close to 1 nanometer, with a tube length that can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder. The way the graphene sheet is wrapped is represented by a pair of indices (*n*, *m*) called the chiral vector. The integer’s *n* and *m* denote the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. If *m*=0, the nanotubes are called "zigzag". If “n” and “m” is same, then the nanotubes are called "armchair". Otherwise, they are called "chiral".

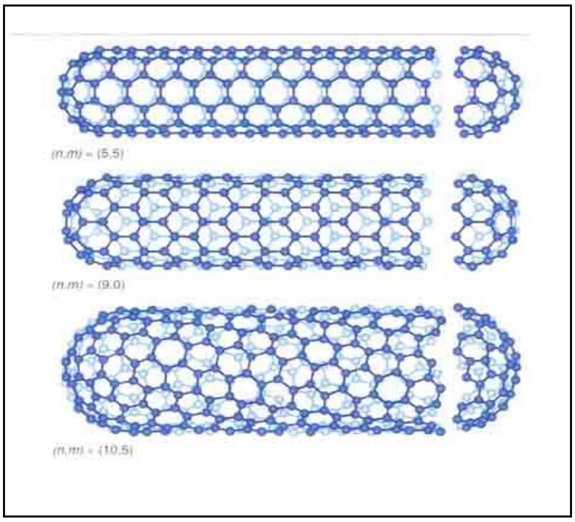

Figure 2: Structure of CNT

2) Multi-walled:

Multi-Walled Nanotubes (MWNT) consists of multiple rolled layers (concentric tubes) of graphite. There are two models which can be used to describe the structures of multi-walled nanotubes. In the *Russian Doll* model, sheets of graphite are arranged in concentric cylinders, e.g., a (0, 8) single-walled nanotube (SWNT) within a larger (0, 10) single-walled nanotube. In the *Parchment* model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.3 Å (330 pm).

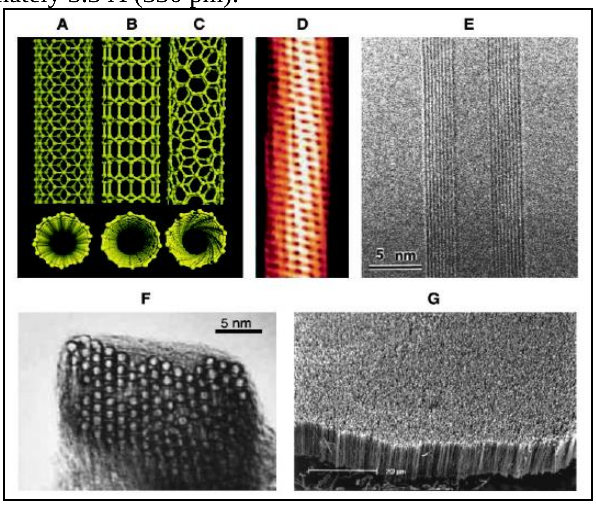

Figure 3**:** Schematic illustrations of CNTs

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Schematic illustrations of the structures of (**A**) armchair, (**B**) zigzag, and (C) chiral SWNTs as shown in figure 3. Projections normal to the tube axis and perspective views along the tube axis are on the top and bottom, respectively. (**D**) Tunneling electron microscope image showing the helical structure of a 1.3-nm-diameter chiral SWNT. (**E**) Transmission Electron Microscope (TEM) image of a MWNT containing a concentrically nested array of nine SWNTs. (**F**) TEM micrograph showing the lateral packing of 1.4-nm-diameter SWNTs in a bundle. (**G**) Scanning Electron Microscope (SEM) image of an array of MWNTs grown as a nanotube forest

Synthesis:

1) Arc discharge:

During this process, the carbon contained in the negative electrode sublimates because of the high discharge temperatures. The yield for this method is up to 30 percent by weight and it produces both single- and multi-walled nanotubes with lengths of up to 50 micrometers.[2]

2) Laser ablation:

In the laser ablation process, a pulsed laser vaporizes a graphite target in a high-temperature reactor while an inert gas is bled into the chamber. Nanotubes develop on the cooler surfaces of the reactor as the vaporized carbon condenses. A water-cooled surface may be included in the system to collect the nanotubes.

3) Chemical Vapor Deposition (CVD):

During CVD, a substrate is prepared with a layer of metal catalyst particles, most commonly nickel, cobalt [3], iron, or a combination[4]. The diameters of the nanotubes that are to be grown are related to the size of the metal particles. This can be controlled by patterned (or masked) deposition of the metal, annealing, or by plasma etching of a metal layer. The substrate is heated to approximately 700°C. To initiate the growth of nanotubes, two gases are bled into the reactor: a process gas (such as ammonia, nitrogen or hydrogen) and a carbon-containing gas (such as acetylene, ethylene, ethanol or methane). Nanotubes grow at the sites of the metal catalyst; the carbon-containing gas is broken apart at the surface of the catalyst particle, and the carbon is transported to the edges of the particle, where it forms the nanotubes. Of the various means for nanotube synthesis, CVD shows the most promise for industrial-scale deposition, because of its price/unit ratio, and because CVD is capable of growing nanotubes directly on a desired substrate.

4) Natural, incidental, and controlled flame environments:

Carbon nanotubes are not necessarily products of high-tech laboratories; they are commonly formed in such mundane places as ordinary flames, produced by burning methane, [5] ethylene, [6] and benzene, [7] and they have been found in soot from both indoor and outdoor air. [8] However, these naturally occurring varieties can be highly irregular in size and quality because the environment in which they are produced is often highly uncontrolled.

Kinetic Mechanism:

Multi-Walled Nanotubes, multiple concentric nanotubes precisely nested within one another, exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell thus creating an atomically perfect linear or rotational bearing. This is one of the first true examples of molecular nanotechnology, the precise positioning of atoms to create useful machines. Already this property has been utilized to create the world's smallest rotational motor. Future applications such as a gigahertz mechanical oscillator are also envisaged.

Applications:

A) Current:

1) Solar cells: Solar cells developed at the New Jersey Institute of Technology use a carbon nanotube complex, formed by a mixture of carbon nanotubes and carbon buckyballs (known as fullerenes) to form snake-like structures. Buckyballs trap electrons, although they can't make electrons flow. Add sunlight to excite the polymers, and the buckyballs will grab the electrons. Nanotubes will then be able to make the electrons or current flow.

2) Ultra capacitors: MIT Laboratory for Electromagnetic and Electronic Systems uses nanotubes to improve ultracapacitors. The activated charcoal used in conventional ultracapacitors has many small hollow spaces of various size, which create together a large surface to store electric charge. But as charge is quantized into elementary charges, i.e., electrons, and each such elementary charge needs a minimum space, a significant fraction of the electrode surface is not available for storage because the hollow spaces are not compatible with the charge's requirements. With a nanotube electrode the spaces may be tailored to size few too large or too small and consequently the capacity should be increased considerably.

B) Other:

1) Carbon nanotubes have been implemented in nanoelectromechanical systems, including mechanical memory elements (NRAM being developed by Nantero Inc.) and nanoscale electric motors

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2) Carbon nanotubes have been proposed as a possible gene delivery vehicle and for use in combination with radiofrequency fields to destroy cancer cells.[3]
3) A nanoradio, a radio receiver consisting of a single nanotube, was demonstrated in 2007.
4) In 2008 it was shown that a sheet of nanotubes can operate as a loudspeaker if an alternating current is applied.
5) The nanotubes would effectively stop the bullet from penetrating the body
6) Nitrogen-doped carbon nanotubes may replace platinum catalysts used to reduce oxygen in fuel cells.

Conclusion:

Carbon nanotubes are allotropes of carbon with numerous outstanding properties. Other than strength, carbon nanotubes have electrical, thermal and many more useful properties. These numerous characteristics make them very desirable in many fields — nanotechnology, electronics, optics, architecture and the medical field.

Nanotubes, depending on their structure, can be metals or semiconductors. They are also extremely strong materials and have good thermal conductivity. The above characteristics have generated strong interest in their possible use in nano-electronic and nano-mechanical devices.

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