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Review Paper

A Review: Carbon Nanotubes (Preparation, Properties, and Biomedical Applications)

Rusul K. Ismail[1], Shahlaa M. Abd Al Hussan[2*]

[1] *College of Dentistry, University of Diyala, Ba'aqubah, Diyala, 32001, Iraq*
[2] *Ministry of Education, Diyala Education Directorate, Diyala, 32001, Iraq*
[*] **Corresponding author**: shahlamn91@yahoo.com

Abstract

One of the most significant areas of nanotechnology is carbon nanotubes. Because of their special properties and cylindrical structure, carbon nanotubes are employed in nanotechnology applications. Their many qualities, such as stiffness, strength, and surface area, have generated interest in the pharmaceutical industry. Single-walled nanotubes and multiple-walled nanotubes are the two types of CNTs. There are several techniques for creating CNTs, including chemical deposition, laser ablation, and arc discharge. These nanotubes are employed in drug delivery and diagnostic systems. Because of its many applications in medicine delivery, it is critical to understand the toxicities of carbon nanotubes and how to handle any problems that may arise. Much research has lately focused on the mechanism of carbon nanotube biodegradation. Single- and double-walled carbon nanotubes must be a safer and more effective way to distribute medications.

Keywords

Carbon Nanotubes, Biological Degradation, Single and Multiple-Walled Nanotubes, Nanomaterials

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1. INTRODUCTION

As is well known, man has learned a great deal from the universe's natural phenomena. Man has created several methods for improved technology with the aid of natural phenomena. Even yet, his comprehension skills and production methods are rudimentary. By simply developing the ability to comprehend the natural phenomena that occur in the world in one form or another, man always attempts to become closer to nature (Bhushan, 2004). We can clearly see how far we have come from the natural technology that occurs in the cosmos by comparing technological advancements with natural phenomena. Modern technology has advanced significantly in the area of energy storage, but it will never match the efficiency of natural processes like photosynthesis (Anajwala et al., 2010). Factory-based water purifying systems are not as effective as those found in watermelons and coconuts. The efficiency of the human brain is a hundred thousand times greater than that of the incredibly fast computers of today. Compared to technological equipment like very fast computers, it has a larger capacity for storing information. In terms of the camera industry, contemporary cameras are insignificant to the average person. Compared to high-magnification cameras, the human eye can produce more colorful pictures of things. Finally, the dog's olfactory receptors are far more sensitive than the extremely sensitive sensors created by contemporary technology. They are far more responsive and sensitive than sensors made using contemporary technology (Raj et al., 2013; Sattler, 2010). One definition of nanotechnology is the study, comprehension, and manipulation of materials in at least one dimension between 1 and 100 nm. The material exhibits new uses at this dimension scale, and new chemistry and physics can be produced. Compared to individual atoms, molecules, or bulk matter, materials at the nanoscale have fundamentally and dramatically different physical, chemical, and biological properties. When compared to devices manufactured at the bulk level, the devices being synthesized within these ranges exhibit superior efficiency. One billionth of a meter is called a nanometer, and its numerical representation is 10-9m or 10Å, (Lone et al., 2019; De Volder et al., 2013). One hundred fifty thousand nanometers would fit across the width of a human hair. Nanoparticles typically range in size from 1 to 100 nm. Science (biology, chemistry, and physics), information technology (computer programming), engineering (electronics and design), and mathematics are all heavily involved in the extremely complicated topic of nanotechnology. The primary goal of this technology is to comprehend and develop redesigned materials, tools, and systems that display the new, enhanced qualities. It is sometimes referred to as size impact technology, since the dimension scale alters several features. The same material may be used in a variety of ways depending on the dimension level thanks to nanotechnology.

We are creating various materials atom by atom using nanotechnology (Kroto et al., 1985; Iijima and Ichihashi, 1993).

Nanotechnology has the potential to totally transform and reinvent a wide range of industries and technological sectors, including transportation, biotechnology, homeland security and national defense, energy, agriculture, aerospace, information technology, and the environment. Applications that will have an influence on our world may now be identified thanks to advancements in discovery in some of these fields. The field of nanotechnology is one that is currently developing and is anticipated to continue to advance in the future. The world's structure and appearance are being altered by this technology. According to the application point of view, new nanomaterials are being created (Boehm, 1997; Song and Cai, 2012). Among these nanomaterials are carbon nanotubes (CNTs). It is regarded as 21st-century material and is gaining a lot of interest from researchers and experts. Fullerenes were found by accident, as is well known in the history of scientific discoveries. In 1985, Kroto and Smalley found strange results in the mass spectra of carbon samples that had evaporated. Fullerenes were found on the same day that it was demonstrated that they were stable in the gas phase. Fullerenes are a kind of molecule. Fullerenes were found on the same day that it was demonstrated that they were stable in the gas phase (Lone et al., 2017; Paradise and Goswami, 2007). Different from graphite and diamond, fullerenes are a molecular form of carbon. Because of its similarity to the geodesic dome, "fullerenes" were named after the architect Richard Buckminster Fuller. Fullerenes consist of dozens to hundreds of carbon atoms arranged in spherical, ellipsoid, or cylindrical shapes. Buckminsterfullerene (C_{60}), a spherical fullerene composed of precisely sixty carbon atoms, resembles a soccer ball and is sometimes termed a "buckyball." "Bucky tubes," or, more frequently, "nanotubes," are the names given to cylindrical fullerenes. The ends of a nanotube can be capped with one hemisphere of a Buckyball.

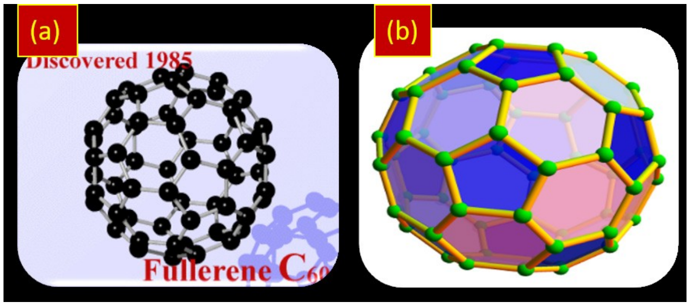

Figure 1. Shows the Structures of Fullerene in (a) and (b)

Buckyballs may be employed as medicine delivery systems or as diagnostic instruments. Additionally, they may be used as catalysts, superconductors, tips for scanning tunneling microscopes, etc. Fullerene's schematic diagram is displayed in Figure 1(a and b) (Zeng et al., 2009; Kato et al., 2003). The graphene sheet is thought to be rolled in order to create Carbon Nanotubes (CNTs). Graphene is the name given to the single layer of graphite. Conversely, there is just a weak link between the graphite layers. An estimated 0.34 nm separates the layers. Another name for graphene is zero band gap semiconductors. Because of its extremely weak interlayer coupling, graphite is a soft substance.

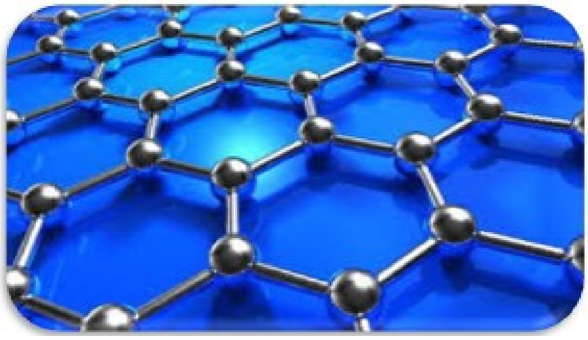

Figure 2. Single Graphene Layer

As a result, graphite is utilized in writing. Figure 3 displays the graphene sheet with the carbon atoms bound to one another. Iijima introduced some discoveries of elongated concentric layers, which he called carbon nanotubes, using transmission electron microscopy. Graphene that has been flawlessly rolled into hollow, tube-shaped cylinders is known as a carbon nanotube (CNT). The diameter of CNTs is in the region of nanometers.

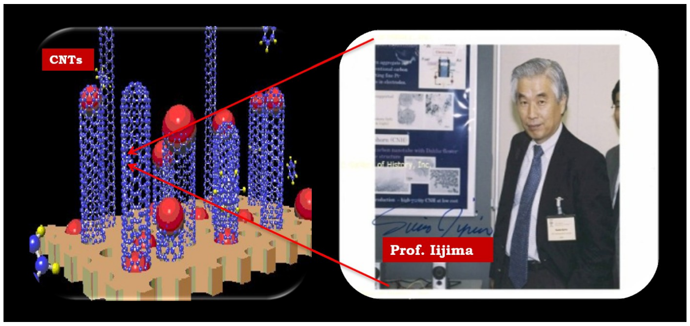

Figure 3. CNTs and Their Discoverer Prof. Iijima

Thus, in 1991, Iijima found structurally well-ordered carbon nanotubes (CNTs) and thoroughly described their architectures. Figure 3 displays the CNTs along with their discoverer. The graphene sheet may be folded in a variety of ways. A wide variety of carbon nanotube architectures are feasible because of the degree of helicity variation. Single-walled carbon nanotubes (SWCNTs) are carbon nanotubes (CNTs) consisting of a single graphene sheet, whereas multiwall CNTs (MWCNTs) are built of more than two graphene sheets.

The modification of helicity affects the electrical structure of CNTs (Klinke et al., 2002; Seidel et al., 2004). The tube diameter (d) and chiral angle are the two parameters that best define the structure of CNTs. C = na1+ma2 is the definition of the chiral vector. In the two-dimensional hexagonal lattice, the a1 and a2 may be characterized as unit vectors. Figure 4(a) displays all of the parameters. The carbon atoms in a single graphene sheet

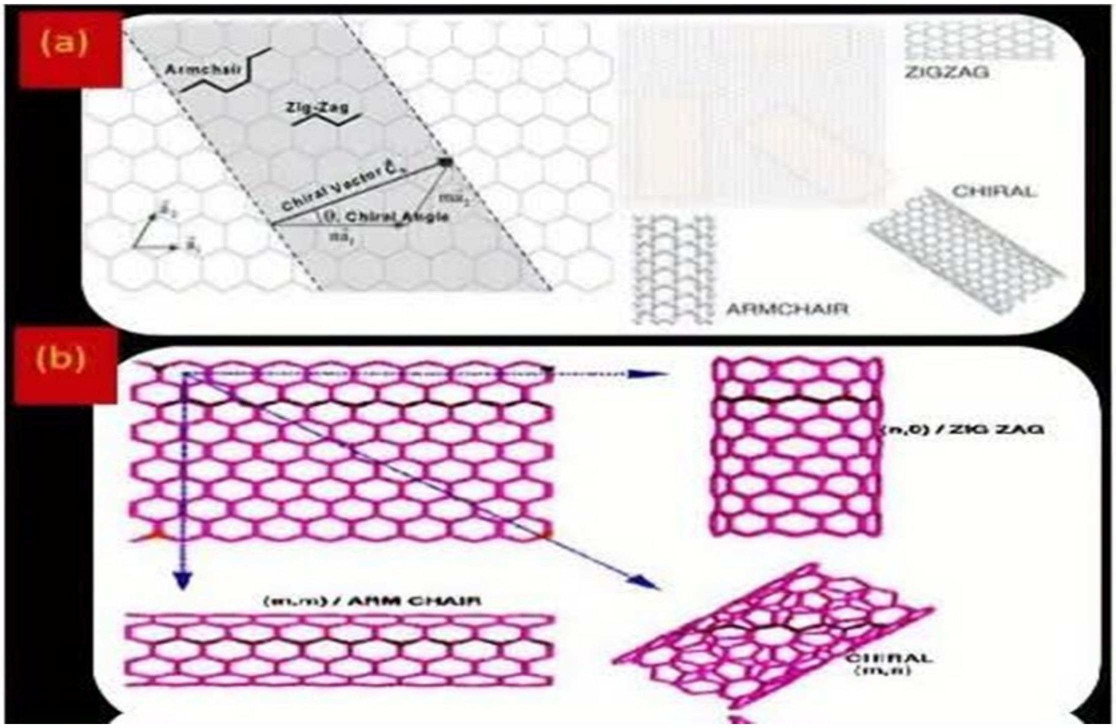

Figure 4. (a) CNT Properties; (b) Graphene Sheet Helacity

are joined to one another in a hexagonal pattern. Figure 4(b) illustrates the graphene layer and the rolling process.

The dimension d and the chiral angle (θ) often determine the characteristics of CNTs. The graphene sheet's wrapping pattern is represented by the pair of indices. The integers n and m indicate how many unit vectors there are in each of the two directions on the graphene sheet. The pair of (n, m) indices are commonly used to describe CNTs (Kumar et al., 2014; Govindaraj and Rao, 2006). The structure of SWCNTs is specified by the (n, m) indices. Depending on the parameters of n and m, different CNT666 structures are produced by rolling the graphene in different ways. Whereas the CNTs with notation (n, 0) are known as zigzags and have an angle (θ) of zero (00), the CNTs with notation (n, n) are termed armchairs and have an angle (θ) of 300. CNTs with the symbol n, m are referred to as chiral, and their angles range from 00 to 300 (Iijima and Ichihashi, 1993; Lone et al., 2017).

2. TYPES OF CARBON NANOTUBES

2.1 Single Wall Carbon Nanotubes

Graphite tubes are known as single-wall carbon nanotubes, or SWCNTs. They are produced using a single graphene wall that is cylindrical. Graphene is a single layer of carbon atoms that makes up the tube's wall. SWCNTs typically have a diameter of 0.6 to 5 nm and a length of up to a micrometer. Compared to MWCNTs, Single Wall Carbon Nanotubes (SWCNTs) are far more difficult to develop. CNTs' excellent flexibility allows them to be bent, twisted, and flattened without breaking (Kumar et al., 2014; Paradise and Goswami, 2007). SWCNTs' unusual structure gives them unique mechanical and electrical characteristics. These exceptional qualities enable their usage in a variety of cutting-edge commercial applications, including logic components, field-emission displays, nanocomposite materials, and nanosensors. These substances might be regarded as the foundation of electronic manufacturing in both current and upcoming technologies. Their structures and characteristics are well-defined (Kato et al., 2003; Dasari et al., 2015).

The ends of the tube composed of rolled graphene stay open, but the synthesis of CNTs is capped by either curved graphene or a metal particle that acts as a catalyst. To give a graphene sheet a positive curvature, pentagons must be put into the sheet. To shut one end of a Carbon Nanotube (CNT) and to make a hemispherical dome of a curved graphene, such as half of the C60 fullerene, six pentagons are needed. Three single-wall carbon nanotube structures made of graphene sheets are depicted in Figure 5 (Sharma et al., 2014; Majzlíková et al., 2015).

2.2 Multi Wall Carbon Nanotubes

Multiwall Carbon Nanotubes (MWCNTs) are created by rolling many graphene sheets in a concentric pattern. There is variation in the quantity of sheets rolled in a concentric manner. On average, rolled graphene sheets have an interlayer spacing of 0.344 nm. Multi Wall Carbon Nanotubes (MWCNTs) typically have sizes between 4 and 50 nm. The unit of measurement is micrometer (μm). MWCNTs have tiny, central chambers that range in diameter from 2 to 10 nm. Compared to SWCNTs, MWCNTs grow more easily. However, because MWCNTs are

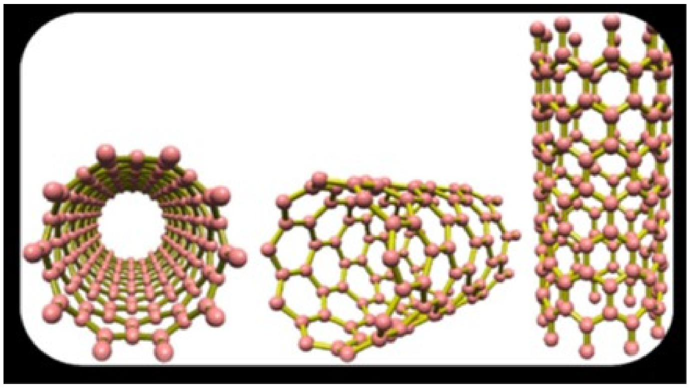

Figure 5. Three Different Structures of SWCNTs

more complicated and varied, it is highly challenging to investigate their structures. Large flaws in MWCNTs can change their characteristics and limit their use in cutting-edge technologies. Both metallic and semiconducting CNTs are possible. The architectures of MWCNTs are seen in Figure 6.

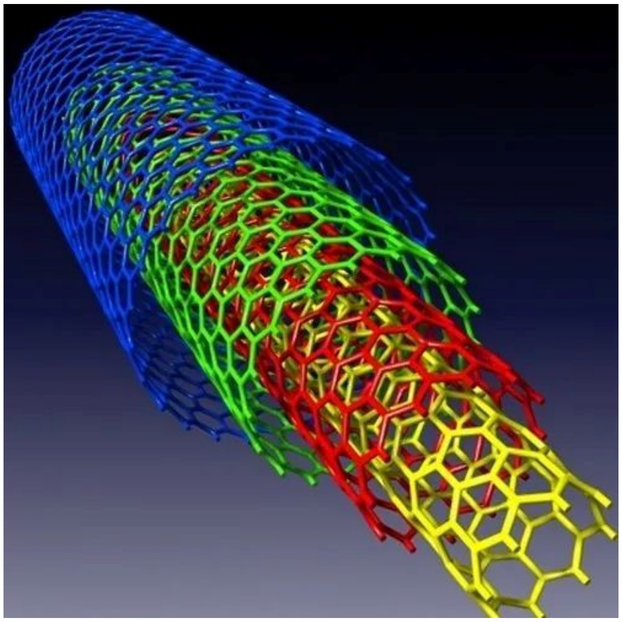

Figure 6. Multi Wall Carbon Nanotubes

The main advantage of Multi Wall Carbon Nanotubes (MWCNTs) over Single Wall Carbon Nanotubes (SWCNTs) is their ease of preparation. In addition to having a cheap cost per unit, they can improve chemical and thermal stability (Morsi et al., 2015; Manohara et al., 2005).

3. METHODS OF SYNTHESIS OF CARBON NANOTUBES

Carbon nanotubes may be formed in a variety of ways. Carbon is typically initially introduced into a gaseous phase and then condensed in all carbon nanotube fabrication techniques. Either solid graphite or a gaseous substance like hydrocarbon serves as the carbon source for the formation of carbon nanotubes. A metal catalyst, such as iron (Fe) or nickel, is often required for the formation of single wall carbon nanotubes. It is possible to generate multiwall carbon nanotubes without a catalyst. According to the literature review, there are three primary methods for CNT development. The three primary methods are chemical vapor deposition (CVD) technique, laser ablation technique, and arc discharge technique (Seidel et al., 2004; Kumar et al., 2013; Sloan and Green, 2000; Zhou et al., 2017).

3.1 Arc Discharge

A novel solid form made of slightly disordered hexagonal packing of soccer-ball-shaped C60 molecules was synthesized in 1990 by Kratschmer and Huffman using an arc discharge process. The highest-quality nanotubes are produced by it (Kong et al., 2001; Ye et al., 2004; Krätschmer et al., 1990). In the arc discharge method, two graphite rods are positioned in an enclosure containing an inert gas (such as argon or helium) at low pressure (between 50 and 700 mbar), and a current of around 50 amps is transmitted between them. As electrodes, the carbon rods are maintained at various potentials. The electrodes are maintained at a distance of 1 mm during the procedure, which takes around a minute, while the anode is pushed near to the cathode until an arc forms.

Following the chamber's depressurization and cooling, the nanotubes and their byproducts can be gathered. The cathode is where the majority of nanotubes deposit. When Co, Ni, or another metal is introduced to the anode, single-walled nanotubes are created (Figure 7).

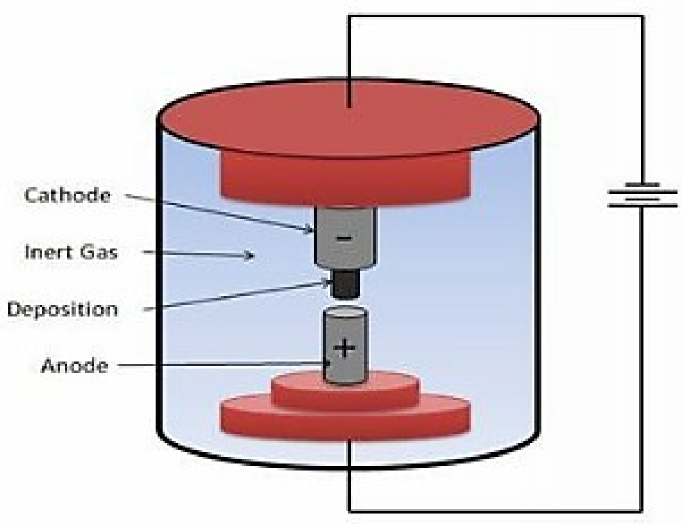

Figure 7. Arc Discharge Method

Using two regular graphite electrodes, a method that creates single-walled CNTs by doping the electrode with metal catalysts such as Ni, Fe, Mo, or Co may be modified to create mostly multiwall CNTs. When these metals encourage the breakdown of gaseous molecules into carbon, the tube starts to form with a metal particle at the tip (Brenner, 1990; Calvert, 1992). Although arc discharge is the simplest method for creating carbon nanotubes, its modest output of CNTs hinders its use as a large-scale production technology. Large-scale MWNT using a variation of the conventional arc discharge approach was described by Ebbensen Ajayan (Ebbesen and Ajayan, 1992).

3.2 Laser Ablation

Richard E. Smalley and his team grew high-quality nanotubes using laser ablation for the first time in 1995. A carbon target put in a tube furnace (Figure 8) heated to 1200°C is ablation-treated by intense laser pulses (Komarov and Mironov, 2004). In order to transport the developed nanotubes to the copper collector, an inert gas, such as argon or helium, passes through the chamber during the procedure. The nanotubes and their byproducts, such as fullerenes and amorphous carbon covering on their sidewalls, may be gathered once the chamber has cooled. Both techniques create multi-walled nanotubes when pure carbon is used, and single-walled carbon nanotubes are created when a catalyst such as iron, yttrium, sulfur, nickel, and molybdenum is added (Journet et al., 1997). About 28% of the carbon anode evaporates because of the extremely high temperatures used in these procedures, which may reach up to 4000°C during the arc discharge (Isaacs et al., 2010).

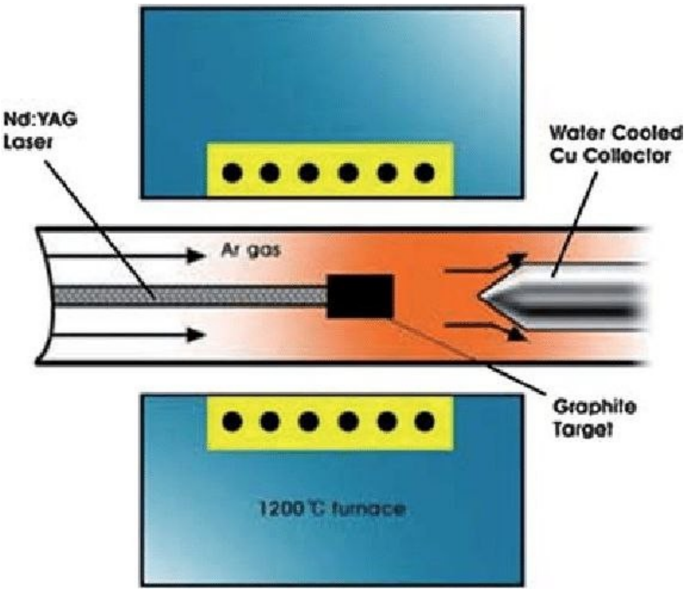

Figure 8. Laser Ablation Setup

Both the operating principle and the production's advantages and disadvantages are somewhat comparable for the two approaches that are roughly depicted in Figures 7 and 8. These days, the synthesis seldom ever uses these techniques. The ensuing highly twisted and disorganized nanotubes, the evaporation of the carbon supply, and the extremely high temperatures involved are the causes. Furthermore, because of the short process timeframes, only the synthesis of the short nanotubes is feasible; no structure, patterning, or substrate growth are conceivable. Furthermore, a significant quantity of purification is required. Other approaches were created to deal with this problem.

3.3 Chemical Vapor Deposition

Carbon nanotubes were created in this manner only in 1993, while reports of catalytic chemical vapor deposition of carbon date back to 1959 (Walker et al., 1959; José-Yacamán et al., 1993). Chemical vapor deposition (CVD) can produce large quantities of unpurified nanotubes. The most basic kind of chemical vapor deposition involves the use of supported transition metal catalysts to catalytically break down hydrocarbon or carbon monoxide feedstock. This two-step procedure involves applying the catalyst to the substrate first, followed by either chemical etching or heat annealing to activate it. Ammonia is used to make an etchant. Metal catalysts made of Ni, Fe, or Co are used. After that, the source of carbon is positioned within the reaction chamber's gas phase. After that, a source of energy like the plasma or a heated coil is used to decrease the carbon molecule to its atomic level.

On top of this metal catalyst, nanotubes will develop as the carbon diffuses toward the catalyst-coated substrate. The carbon sources employed include acetylene, carbon monoxide, or methane (Figure 9). The temperature range used to produce nanotubes is between 650 and 9000°C. The average yield is 30 percent (Varshney, 2014; Rokade et al., 2021; Sinnott and Andrews, 2001; Paradise and Goswami, 2007). Because CVD has previously been well studied and produces satisfactory results on an industrial scale, it is frequently employed for industrial reasons.

4. MECHANISM OF DRUG RELEASE THROUGH CARBON NANOTUBES: PROPERTIES OF CARBON NANOTUBES

4.1 Chemical Reactivity

When compared to a graphene sheet, the CNT's surface curvature increases its chemical reactivity. The reactivity of carbon nanotubes is closely correlated with an enhanced curvature that results in a pi-orbital mismatch. Consequently, it is essential to differentiate between a nanotube's sidewall and end caps. With the same purpose, reactivity increases with decreasing nanotube diameter. It was recently demonstrated that end caps and sidewalls may both undergo covalent chemical modification. For example, the solubility of CNTs in different solvents may be controlled using this technique. However, because the samples are still too impure, it is difficult to directly examine how chemical changes affect nanotube behavior (Peng et al., 2003).

4.2 Electrical Conductivity

In accordance with their chiral vector, short-diameter nanotubes of carbon can be either metallic or semiconducting. The differences in conducting qualities are caused by the molecular structure, which produces a distinct band structure and, as a result, a varying band gap. The variations in conductivity may be immediately inferred from the grapheme sheet's characteristics. A (n, m) nanotube is metallic if $(n=m)$ or $(n\text{-}m)$ equates to $3i$, where (i) represents an integer while (n and m)define the

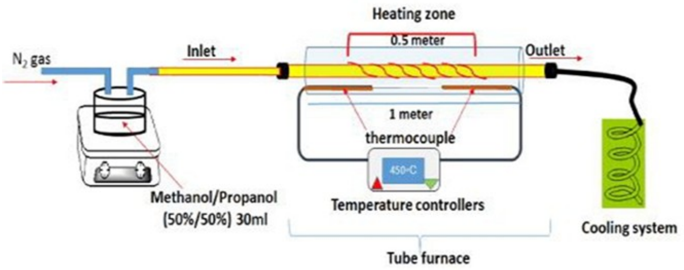

Figure 9. Chemical Vapor Disposition (Paliwal et al., 2020)

nanotube, respectively. It has been shown that the quantum mechanical parameters influencing the resistance to conduction are independent of the nanotube's length (Peng et al., 2003).

4.3 Optical Activity

In their axial orientation, carbon nanotubes have a rather high Young modulus. Overall, the nanotube is extremely flexible because of its length. Therefore, these substances could be suitable for use in composite materials that need anisotropic characteristics (Peng et al., 2003).

4.4 Mechanical Strength

Carbon nanotubes have a comparatively high Young modulus in their axial orientation. The length of the nanotube makes it incredibly flexible overall. As a result, these compounds could be suitable for application in composite materials that need anisotropic characteristics (Peng et al., 2003).

4.5 Thermal Properties

It is expected that all nanotubes would exhibit superior thermal conductors along the tube and great thermal insulators laterally to the tube axis, a property known as "ballistic conduction." While copper, a metal noted for its exceptional thermal conductivity, transmits 385 Wm-1K-1, carbon nanotubes are predicted to be able to transmit up to 6000 Wm-1K-1 at room temperature. Carbon nanotubes are estimated to have a thermal stability of 750°C in air and 2800°C in a vacuum. The thermal expansion of CNTs will be primarily isotropic, in contrast to that of normal graphite fibers, which are significantly anisotropic. This might be advantageous for carbon-based composites. Extremely low thermal expansion coefficients are expected for low-defect CNTs (Pop et al., 2006).

5. TOXICOLOGICAL CONSIDERATION OF NANOTUBES

According to research about pure nanotubes' toxicity in cell culture, SWCNTs induce oxidative stress, which makes CNTs poisonous to cells (Kagan et al., 2004). Functionalized and highly water-soluble pristine nanotubes are less cytotoxic than non-functionalized pristine nanotubes (Magrez et al., 2006). It has also been shown that CNT morphological changes and flow cytometry studies are useful for detecting cytotoxic characteristics. Furthermore, the toxicity of CNTs is correlated with their length. In the medical industry, CNTs are thought to be the best potential drug delivery vehicles. The resulting toxicity, on the other hand, is not well understood and is subject to much research. The two most significant and frequent reasons for the harmful impacts of nanoparticles are their large surface area and inherent toxicity. Because they may travel from the site of deposition and evade the body's natural defenses against phagocytic invasion, nanoparticles smaller than 100 nm are believed to pose a greater risk to the respiratory system. Furthermore, it can alter the structure of proteins that cause immunologic and inflammatory responses, which could affect tissues' ability to function normally (Donaldson et al., 2004). The toxic effects of CNTs are frequently caused by the length of the CNTs and the presence of ferric impurities (Cheng et al., 2009). Additional parameters influencing the toxicity of CNTs include: (physical shape, structure, surface charge, surface chemistry, aggregation state, degree of functionalization, and purity of the samples) under examination (Sayes et al., 2006). The degree of functionalization and the existence of functional groups also influence the toxicity of CNTs. It has been shown that impurities like metallic nanoparticles and amorphous carbon, which might act as additional sources of toxicity, are present in large-scale production of pure, unmodified carbon nanotubes. Numerous investigations have shown that SWCNTs can induce cellular reactions by activating molecular pathways linked to oxidative stress (Thurnherr et al., 2011; Rahamathulla et al., 2021).

6. CHARACTERIZATION OF CARBON NANOTUBES (CNTs)

CNTs may be produced using a variety of techniques, each of which yields a somewhat different material in terms of diameter, length, chirality, purity, catalysts, impurity species, and defects. Additionally, although purifying techniques raise the percentage of carbon nanotubes (CNTs) in a sample, they can alter the CNTs themselves. They may shorten their length, change their functional groups, open one or both of their ends, or occasionally result in defects (Hu et al., 2001; Mawhinney et al., 2000). Although they have a graphitic structure, carbon nanotubes are nanometric carbon particles that also include a lot of impurities. Since its applications would need validation of qualities and function, it is crucial to characterize the CNTs in the sample in order to ascertain their number, quality, and properties (Kingston, 2007). There are issues with the regulated and large-scale production of CNTs that need to be resolved. All of these tubes' characteristics must be identified. Techniques including transmission electronic microscopy, X-ray diffraction, infrared, and UV-Vis are mostly global characterization methods that may be used to examine the morphological and structural characteristics of carbon nanotubes.

6.1 Electron Microscopy (SEM and TEM)

Any nanomaterial must be characterized using: (electron microscopy, namely scanning and transmission electron microscopy), which provides direct observation of the (size, shape, and structure) (Figures 10 and 11). The TEM approach is clearly helpful for measuring both the outer with inner radius and linear

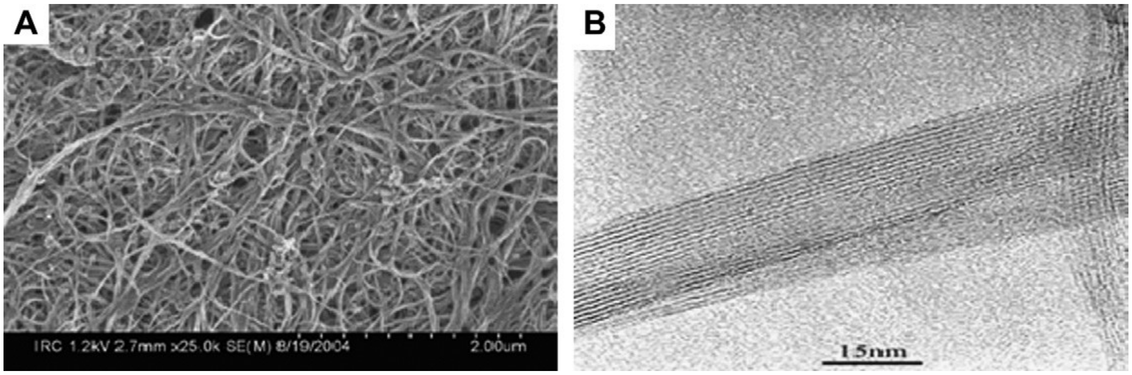

Figure 10. SWCNT Electron Micrographs. (A) SWCNT SEM. (B) SWCNT TEM (Kingston et al., 2004)

electron coefficient of absorption of the MWCNTs according to Lambert's law modeling and the intensity throughout a CNT segment (Gommes et al., 2003). When MWCNTs were studied using this approach both before and after annealing, the electron absorption coefficient significantly increased; this rise can be attributed to a more organized arrangement of the wall material. The intershell spacing of MWCNTs was also investigated using high-resolution TEM images (Kiang et al., 1998). It is discovered that the intershell gap varies with CNT diameter, ranging from 0.34 to 0.39 nm (Figure 12 A–C). These numbers do, however, slightly exceed the graphite interplanar distance (0.336 nm) (Charlier et al., 1999). This rise is most likely caused by the graphene sheets' altered curvature as a result of the tube radius. The repulsive force increases as a result of this curvature, and the size effect is stronger at tiny diameters (under 10 nm).

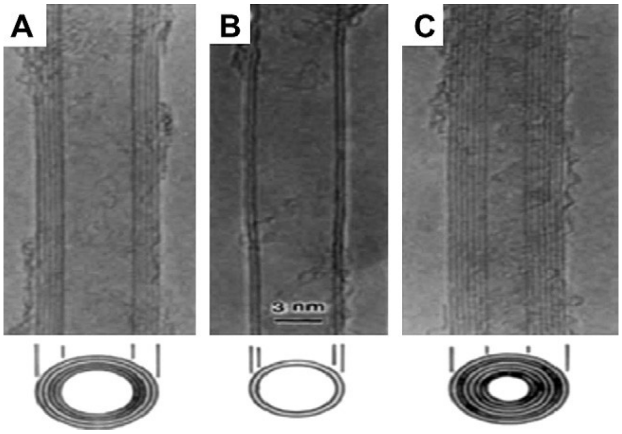

Figure 11. Electron Micrographs Taken During the Initial CNT Report. Graphite's (002) Lattice Pictures are Represented By Parallel Black Lines. Each Tubule is Shown in Cross-Section. (A) A 6.7 nm Diameter Tube Made Up of Five Graphitic Sheets. (B) A Tube with Two Sheets, 5.5 nm in Diameter. (C) A Seven-Sheet Tube with A Diameter of 6.5 nm and the Lowest Hollow Diameter (2.2 nm) (Iijima et al., 1992)

6.2 Diffraction of X-Rays (XRD)

Using this method, some information on the impurities: (structural strain, and interlayer spacing) may be obtained. In contrast to the X-ray incident beam, CNTs may be oriented in a variety of ways. For MWCNTs, different numbers of layers are also seen, along with the distribution of diameters and chiralities. As a result, CNTs are statistically characterized.

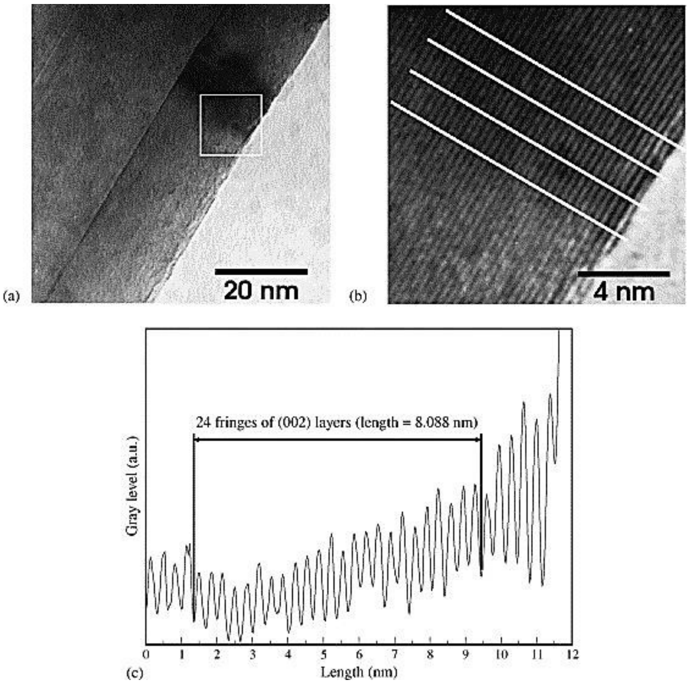

Figure 12. (A) A MWCNT's TEM Picture (Diameter of Approximately 65 nm). Following A Series of Oxidation Procedures, CVD Was Used To Create These Mwcnts. You Can See the Contrast Between the Walls. (B) Expansion of the CNT's Walls. To Determine the Intershell Distance, White Lines Are Utilized. (C) Average Intensity Level Profile of Walls Displaying the Fringes of the (002) Layers Utilized To Calculate The Intershell Spacing. In This Case, the Intershell Spacing is 0.337 ±0.023 Nm, Which is Quite Similar To the Graphite Value

The primary characteristics of the X-ray diffraction pattern of carbon nanotubes (CNTs) are similar to those of graphite because of their inherent characteristics. The XRD structure of MWCNT, which was synthesized using the CVD technique, is shown in Figure 13. It contains a graphite-like peak (0021), from which interlayer spacing can be measured using the Bragg law, as well as a family of (hk0) peaks that result from the honeycomb lattice of a single graphene sheet. As a result, the XRD profile may be used to determine the sample purity but is not helpful in distinguishing microstructural features between the CNTs and the graphite structure (Zhu et al., 2003).

According to X-ray diffraction techniques, straight CNTs that are properly aligned on the substrate surface cannot measure any (002) peaks. When CNTs have a tube axis that is perpendicular to the substrate surface, the incoming X-ray beam is dispersed inside the sample instead of being collected. Consequently, when CNTs are more closely aligned, the (002) peak's intensity drops (Cao et al., 2001). The impact of several factors, including the mean tube diameter, the finite size of the bundles, and the diameter dispersivity of the tubes, has also been investigated using X-ray diffraction. Each of these factors has a major impact on the location and breadth of the (10) peak (Rols et al., 1999; Kuzmany et al., 2001). This characterization technique isn't sample damaging, though.

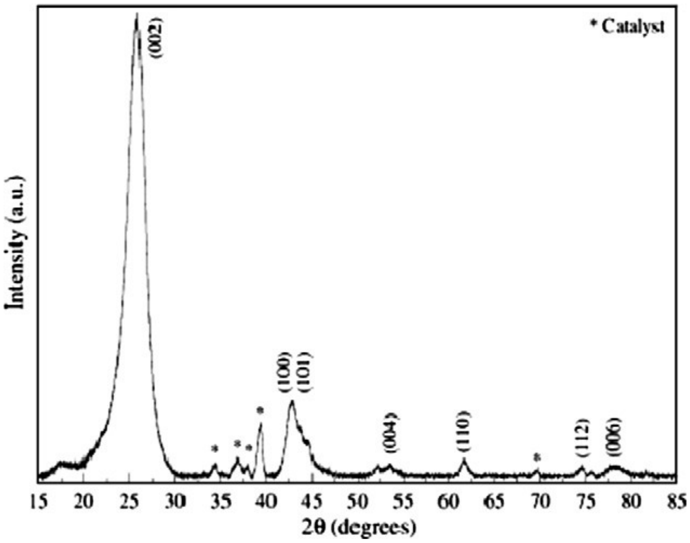

Figure 13. XRD Structure of MWCNT (Diameter Approximately 60 Nm) Produced By CVD. The Wavelength of the Incident X-Ray Is K = 0.154056 Nm. When Using Miller Indices, the Most Notable Bragg Peaks Are Seen. Stars in the CNT Sample Indicate the Existence of Catalysts (Co And Mo)

6.3 (UV-Vis and IR) Absorption Spectroscopy

Unlike other graphitic nanocarbons, carbon nanotubes (CNTs) and SWCNTs in particular have distinct optical absorptions due to their distinct electrical structure. A very helpful method for determining the relative purity of CNT is absorption spectroscopy (Figure 14). Depending on the symmetry, SWCNTs have seven to nine infrared active modes, including chiral, zigzag, and armchair (Kuhlmann et al., 1998). The A_{2u} and E_{1u} modes are the primary active modes (Kuzmany et al., 1998). These phonon modes are detected by MWCNTs at around 868 and 1575 cm^{-1}, respectively, (Kastner et al., 1994; Eklund et al., 1995).

Regardless of the diameters, these modes (about 850 and 1590 cm^{-1}) manifest in every CNT symmetry (Kuhlmann et al., 1998). Two structures, about 874±2 and 1598±3 cm^{-1}, were seen in samples that were mostly composed of SWCNTs. However, those frequencies deviate from normal graphite frequency to higher levels by 5 and 8 cm^{-1}, respectively. IR spectroscopy is frequently employed in CNT characterization to identify contaminants left over from production or compounds encapsulated on the CNT surface. CNTs and organic molecules are the subject of several studies. IR spectroscopy shows all structural changes to the CNTs and identifies the types of substances that have been added to them. The results of MWCNTs' chemical modification by amino acids were described in one research study (Saito et al., 2002). This research falls into two categories: catalytic characteristics of CNTs and characterization of molecules linked to CNTs (He et al., 2004; Yang et al., 2004; Jung et al., 2004; Xu et al., 2003; Liu et al., 2003; Aizawa and Shaffer, 2003; Wang et al., 2004; Pereira et al., 2004). In the oxidative dehydrogenation of ethylbenzene (ODE), a different research observed that CNTs, activated carbon, and graphite samples performed differently in terms of catalytic activity. MWCNTs that have been oxidized before the catalytic tests have the maximum catalytic activity (Pereira et al., 2004). FT-IR also looked at the potential applications of CNTs for the catalytic removal of NO_x (NO, NO_2, NO_3) (Wang et al., 2004). Effective methods for CNTs. Nevertheless, the following difficulties confront these characterization techniques:

1. A CNT sample cannot be fully described by a single approach.
2. Restrictions on the inferences that can be made using each method.
3. The method used for preparing the sample and measurements can make a significant difference.
4. Comparing measurements to a reference makes them more valuable.
5. It is challenging to directly compare CNT produced using various techniques. All of the methods discussed here must be used in conjunction with one another in order to properly characterize CNTs.

7. APPLICATION OF CARBON NANOTUBES

7.1 Carrier for Drug Delivery

Carbon nanohorns (CNHs) are spherical CNT aggregates with an amorphous horn-like shape. Research studies have shown that CNTs and CNHs are promising medication delivery system carriers (Wieckowski et al., 2005).

7.2 Cancer of the Blood

Leukemia is a kind of cancer that usually spreads to the blood, although it can begin in the bone marrow, the soft inside of cer-

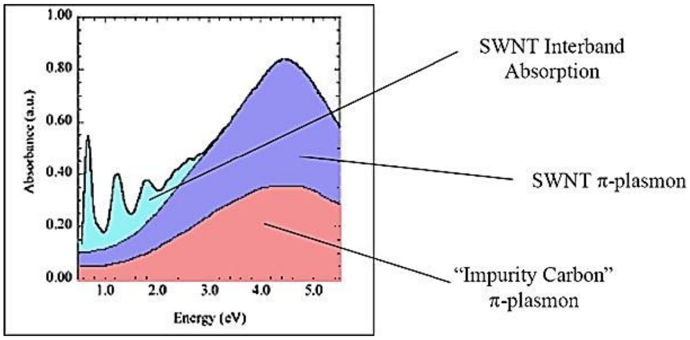

Figure 14. Absorption Spectrum for SWCNT (Itkis et al., 2005)

tain bones. Taghdisi and colleagues created a tertiary daunorubicin compound SWCNT. Additionally, the Sgc8c aptamer targets the blood-based biomarker super molecule aminoalkanoic acid kinase-7, which is linked to cancer. Known as Dau-aptamer SWCNTs, daunorubicin (Dau) can be precisely administered to acute lymphoblastic leukemia. In a flow cytometric analysis, the tertiary complexes were effectively absorbed by human lymphocytes cancer of the blood cells (MOLT-4 cells), but not by U266 malignancy cells. The release of DAU-loaded nanotubes was pH-dependent in a solution with a pH of 5.5, which is extremely slightly acidic. After 72 hours at 37°C, Dau was liberated from the complx, but the tertiary complex of the (Dau-aptamer-SWNTs) remained mostly stable during a comparable comparable keeping at a pH of 7.4 (Taghdisi et al., 2011).

7.3 Breast Cancer

A 20–25% increased risk of invasive carcinomas is associated with overexpression HER2, a human cuticular protein the receptor type2, often referred to as (c-erbB-2 or HER2/neu), often referred to as c-erbB-2 or HER2/neu. Liu and colleagues evaluated the efficacy of paclitaxel (PTX) delivered by SWNT into xenograft growths in mice, finding that it suppressed tumors more effectively than the clinical medication formulation Taxol. In vitro toxicity to cancer cells was equivalent to that of Taxol, and the PTX linked to PEGylated SWNTs showed notable water solubility. An EPR test indicates that SWNT-PTX causes high tumor absorption of the medication because it allows PTX to circulate in the blood for a much longer duration than Taxol and PEG-ylated PTX. Even at modest drug dosages, SWNT-PTX can suppress growth, demonstrating its strong therapeutic efficacy (Liu et al., 2009).

7.4 Liver Cancer

The development of polyamidoaminedendrimer modified carbon nanotubes (dMWCNTs) allowed for the economical treatment of HepG2 cancer cells with antisense c-myc oligonucleotide (asODN). After fifteen minutes of treatment with HepG2 cells, optical maser confocal examination showed that ODN-dMWCNT composites had penetrated into tumor cells. These composites inhibited cell proliferation in a dose- and time-dependent manner and decreased the expression of the C-Myc supermolecule and c-Myccistron. These composites perform better in terms of tumor cell inhibition and transfection efficiency than CNTNH-asODN and dendrimer (asODN) alone (Liu et al., 2009).

7.5 Lymph Node Metastatic

In vitro and in vivo, Yang et al. investigated the possible therapeutic advantages of gemcitabine-loaded magnetic MWCNTs (mMWCNTs) on gemcitabine-loaded magnetic-carbon particles (mACs). The results demonstrate that mACs and mMWNTs dramatically increased GEM toxicity in vivo and prevented lymphatic tissue metastasis, especially when combined with high dosage medications and/or deep-seated in vivo magnets. By fusing the advantages of body fluid treatment combined with magnetic retargeting, the system provide a chance to improve therapeutic outcomes and lessen side effects related to chemotherapeutic medications. When given subcutaneously. However, mMWCNTs-GEM outperformed (mACs-GEM) for the non-destructive prevention of lymphatic tissue dissemination based on the effect of a magnetic field due to the fact that their magnetic moments align due to their super magnet nature on the field of action and creates web magnetization that greatly influences how they interact with the membrane of a cell (Pai et al., 2006).

7.6 Gene Therapy

CNTs will transport a large quantity of therapeutic chemicals, such as DNA and ribonucleic acid, to the disease sites of interest. Gene therapy and ribonucleic acid have a lot of potential for treating cancer. The remarkable flexibility and wire-like structure of carbon nanotubes (CNTs), which have a diameter comparable to that of DNA/siRNA, will influence the transient conformational changes and conformational structure of DNA ribonucleic acid, thereby augmenting its therapeutic effects. The use of amino-functionalized multiwalled carbon nanotubes (MWNT-NH^{3+}) to cure a patient's respiratory organ malignant neoplastic illness model involves the in vivo misuse of siRNA sequences, which leads to light-emitting diode toxicity and necrobiosis. This is believed to work physiologically in vivo by starting an apoptotic cascade that causes the human growth mass to deeply necrotize and simultaneously prolongs the survival of animals harboring malignancies of the human respiratory organs (Meng et al., 2008).

7.7 Immune Therapy

Anti-tumor therapy can sometimes have few side effects and good patient tolerance, which can greatly enhance the prognosis. Chemotherapy suffers from cumulative toxicity and drug resistance. Furthermore, it has been shown that CNTs can increase the antigenicity of the proteins or peptides they contain. Using a (mouse model of H22) liver disease, Xu et al. (2003) examined whether the MWNTs associated with neoplastic lysate supermolecules may improve the effectiveness of a tumor fighting therapy that uses neoplasm cell immunogen (TCV).

7.8 Biomedical Applications

CNTs will be used in a wide range of applications because of a range of antifungal and medicinal properties, their high durability, rapid lepton transfer dynamics, ultra-light weight, chemical immobility, high durability, a variety of antifungal and medication properties, the ability to act as macromolecule carriers, the presence of exposed practical teams, etc. Additionally, they have semi- and golden-semiconducting properties that make them a good material for a number of uses, such as food safety, clinical medicine, and environmental monitoring. CNTs are also essential for the development of sensors that law enforcement may use to combat a range of pathogenic microorganisms and support cancer therapy. CNTs still exhibit a variety of antibacterial properties ((Smart et al., 2006; Dey and Das, 2013).

7.9 Antifungal Therapy

The capacity of MWCNTs with functional groups to suppress the plant pathogenic fungus Fusarium graminearum was evaluated. MWCNT with $-$OH, $-NH_2$, and $-$COOH functionalization prevented fungus spores from elongating and germinating. When MWCNTs were functionalized, germination was three times lower than when they weren't (Wang et al., 2017). Additionally investigated were the antifungal properties of a number of nanoparticles againstthe notorious fungus that causes (Cinerea Botrytis) that thrives on the petals of roses. Water agar surfaces were supplemented with MWCNTs, fullerene, and reduced graphene oxide at varying concentrations (50 and 200 mg/L). The study found that at a dose of 200 mg/L, MWCNTs showed inhibitory effects on the fungus on rose petals (Hao et al., 2017). Another research examined the antifungal effectiveness of the fictionalized amino acid content of the MWCNTs. The study's findings from ten distinct fungus species showed that MWCNTs functionalized with arginine and lysine exhibited more antifungal efficacy than virgin MWCNTs. The enhanced antifungal action is caused by the higher positive charge upon fictionalization. Functionalized MWCNTs with arginine showed somewhat higher activity because arginine has a higher positive charge than lysine (Zare-Zardini et al., 2013).

8. FUTURE PROSPECTIVE

More study is needed to create functionalization and characterization techniques that are acceptable and relatively simple in order to enhance the biodegradation of CNTs. This will help to increase their non-toxicity and biocompatibility. It is crucial to create functionalization and characterization processes for CNTs that are somewhat simpler and more appropriate in order to increase their water solubility, biocompatibility, non-cytotoxicity, and optimum biodegradability. Understanding the toxicological features of CNTs is essential before developing them for use in biomedical applications. It is necessary to create easier techniques for conjugating hydrophilic polymers or other bioactive compounds in order to optimize the benefits of carbon nanotubes. The future of CNTs will largely depend on the safety concerns and our attempts to increase their biocompatibility.

9. CONCLUSIONS

The potential of these structures is constantly being investigated, and a great deal of research is still being done on the traits and capabilities of CNTs. Prior research has demonstrated that the use of single and multiple walled carbon nanotubes for medication delivery is a safer and more effective method. Because it produces extremely pure carbon nanotubes, chemical vapor deposition is the best technique for creating carbon nanotubes. Researchers' interest in carbon nanotubes is growing, and it is expected that they will make further developments soon. Despite the limited number of accessible approaches, useful methods are employed to characterize carbon nanotubes. Information on (interlayer spacing, structural strain, and impurities) may be obtained using X-ray diffraction. Transmission electron microscopy (TEM) is also used to extract a variety of characteristics, including helicity, chiral indices, and intershell spacing. To identify contaminants left over after production or molecules capped on the surface of CNTs, infrared spectroscopy (IR) is frequently utilized.

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REFERENCES

Aizawa, M. and M. S. Shaffer (2003). Silylation of Multi-Walled Carbon Nanotubes. *Chemical Physics Letters*, **368**(1-2); 121–124

Anajwala, C. C., G. K. Jani, and S. V. Swamy (2010). Current Trends of Nanotechnology for Cancer Therapy. *International Journal of Pharmaceutical Sciences and Nanotechnology*, **3**(3); 1043–1056

Bhushan, B. (2004). Micro/Nanotribology and Materials Characterization Studies Using Scanning Probe Microscopy. In *Springer Handbook of Nanotechnology*. Springer, Berlin, Heidelberg, pages 497–541

Boehm, H. P. (1997). The First Observation of Carbon Nanotubes. *Carbon (New York, NY)*, **35**(4); 581–584

Brenner, D. W. (1990). Empirical Potential for Hydrocarbons for Use in Simulating the Chemical Vapor Deposition of Diamond Films. *Physical Review B*, **42**(15); 9458

Calvert, P. (1992). Strength in Disunity. *Nature*, **357**(6377)

Cao, A., C. Xu, J. Liang, D. Wu, and B. Wei (2001). X-Ray Diffraction Characterization on the Alignment Degree of Carbon Nanotubes. *Chemical Physics Letters*, **344**(1-2); 13–17

Charlier, A., E. McRae, R. Heyd, M. F. Charlier, and D. Moretti (1999). Classification for Double-Walled Carbon Nanotubes. *Carbon*, **37**(11); 1779–1783

Cheng, C., K. H. Müller, K. K. Koziol, J. N. Skepper, P. A. Midgley, M. E. Welland, and A. E. Porter (2009). Toxicity and Imaging of Multi-Walled Carbon Nanotubes in Human Macrophage Cells. *Biomaterials*, **30**(25); 4152–4160

Dasari, B. S., W. R. Taube, P. B. Agarwal, M. Rajput, A. Kumar, and J. Akhtar (2015). Room Temperature Single Walled Carbon Nanotubes (SWCNT) Chemiresistive Ammonia Gas Sensor. *Sensors & Transducers*, **190**(7); 24

De Volder, M. F., S. H. Tawfick, R. H. Baughman, and A. J. Hart (2013). Carbon Nanotubes: Present and Future Commercial Applications. *Science*, **339**(6119); 535–539

Dey, P. and N. Das (2013). Carbon Nanotubes: It's Role in Modern Health Care. *International Journal of Pharmacy and Pharmaceutical Sciences*, **5**(4); 9–13

Donaldson, K., V. Stone, C. L. Tran, W. Kreyling, and P. J. A. Borm (2004). Occupational and Environmental Medicine. *Nanotoxicology*, **61**; 727–728

Ebbesen, T. W. and P. M. Ajayan (1992). Large-Scale Synthesis of Carbon Nanotubes. *Nature*, **358**(6383); 220–222

Eklund, P. C., J. M. Holden, and R. A. Jishi (1995). Vibrational Modes of Carbon Nanotubes; Spectroscopy and Theory. *Carbon*, **33**(7); 959–972

Gommes, C., S. Blacher, K. Masenelli-Varlot, C. Bossuot, E. McRae, A. Fonseca, and J. P. Pirard (2003). Image Analysis Characterization of Multi-Walled Carbon Nanotubes. *Carbon*, **41**(13); 2561–2572

Govindaraj, A. and C. N. R. Rao (2006). Synthesis, Growth Mechanism and Processing of Carbon Nanotubes. In *Carbon Nanotechnology*. Elsevier, pages 15–51

Hao, Y., X. Cao, C. Ma, Z. Zhang, N. Zhao, A. Ali, and Y. Rui (2017). Potential Applications and Antifungal Activities of Engineered Nanomaterials Against Gray Mold Disease Agent *Botrytis cinerea* on Rose Petals. *Frontiers in Plant Science*, **8**; 1332

He, B., W. Sun, M. Wang, S. Liu, and Z. Shen (2004). Preparation and Characterization of a Series of Novel Complexes by Single-Walled Carbon Nanotubes (SWNTs) Connected Poly (Amic Acid) Containing Bithiazole Ring. *Materials Chemistry and Physics*, **84**(1); 140–145

Hu, H., P. Bhowmik, B. Zhao, M. A. Hamon, M. E. Itkis, and R. C. Haddon (2001). Determination of the Acidic Sites of Purified Single-Walled Carbon Nanotubes by Acid–Base Titration. *Chemical Physics Letters*, **345**(1-2); 25–28

Iijima, S., P. M. Ajayan, and T. Ichihashi (1992). Growth Model for Carbon Nanotubes. *Physical Review Letters*, **69**(21); 3100

Iijima, S. and T. Ichihashi (1993). Single-Shell Carbon Nanotubes of 1-nm Diameter. *Nature*, **363**; 603–605

Isaacs, J. A., A. Tanwani, M. L. Healy, and L. J. Dahlben (2010). Economic Assessment of Single-Walled Carbon Nanotube Processes. *Journal of Nanoparticle Research*, **12**; 551–562

Itkis, M. E., D. E. Perea, R. Jung, S. Niyogi, and R. C. Haddon (2005). Comparison of Analytical Techniques for Purity Evaluation of Single-Walled Carbon Nanotubes. *Journal of the American Chemical Society*, **127**(10); 3439–3448

José-Yacamán, M., M. Miki-Yoshida, L. Rendón, and J. G. Santiesteban (1993). Catalytic Growth of Carbon Microtubules with Fullerene Structure. *Applied Physics Letters*, **62**(6); 657–659

Journet, C., W. K. Maser, P. Bernier, A. Loiseau, M. L. de La Chapelle, D. S. Lefrant, and J. E. Fischer (1997). Large-Scale Production of Single-Walled Carbon Nanotubes by the Electric-Arc Technique. *Nature*, **388**(6644); 756–758

Jung, D. H., Y. K. Ko, and H. T. Jung (2004). Aggregation Behavior of Chemically Attached Poly (Ethylene Glycol) to Single-Walled Carbon Nanotubes (SWNTs) Ropes. *Materials Science and Engineering: C*, **24**(1-2); 117–121

Kagan, V., A. Potapovich, A. Osipov, D. Schwegler-Berry, E. Kisin, R. Mercer, and A. Shvedova (2004). Iron-Rich Single Walled Carbon Nanotubes Are Effective Catalysts of Oxidative Stress in RAW 264.7 Macrophage Cell Culture Model: Interactions with Inflammatory Response and In Vivo Implications. *Free Radical Biology and Medicine*, **37**; S51–S52

Kastner, J., T. Pichler, H. Kuzmany, S. Curran, W. Blau, D. N. Weldon, and H. Zandbergen (1994). Resonance Raman and Infrared Spectroscopy of Carbon Nanotubes. *Chemical Physics Letters*, **221**(1-2); 53–58

Kato, T., G. H. Jeong, T. Hirata, R. Hatakeyama, K. Tohji, and K. Motomiya (2003). Single-Walled Carbon Nanotubes Produced by Plasma-Enhanced Chemical Vapor Deposition. *Chemical Physics Letters*, **381**(3-4); 422–426

Kiang, C. H., M. Endo, P. M. Ajayan, G. Dresselhaus, and M. S. Dresselhaus (1998). Size Effects in Carbon Nanotubes. *Physical Review Letters*, **81**(9); 1869

Kingston, C. (2007). Challenges in the Characterization of Carbon Nanotubes: The Need for Standards. In *Molecular and Nanomaterial Architectures Group Tri-National Workshop on Standards for Nanotechnology*

Kingston, C. T., Z. J. Jakubek, S. Dénommée, and B. Simard (2004). Efficient Laser Synthesis of Single-Walled Carbon Nanotubes Through Laser Heating of the Condensing Vaporization Plume. *Carbon*, **42**(8-9); 1657–1664

Klinke, C., R. Kurt, J. M. Bonard, and K. Kern (2002). Raman Spectroscopy and Field Emission Measurements on Catalytically Grown Carbon Nanotubes. *The Journal of Physical Chemistry B*, **106**(43); 11191–11195

Komarov, F. F. and A. M. Mironov (2004). Carbon Nanotubes: Present and Future. *Physics and Chemistry of Solid State*, **5**(3); 411–429

Kong, J., M. G. Chapline, and H. Dai (2001). Functionalized Carbon Nanotubes for Molecular Hydrogen Sensors. *Advanced Materials*, **13**(18); 1384–1386

Krätschmer, W., L. D. Lamb, K. H. D. R. Fostiropoulos, and D. R. Huffman (1990). Solid C60: A New Form of Carbon. *Nature*, **347**(6291); 354–358

Kroto, H. W., J. R. Heath, S. C. O'Brien, R. F. Curl, and R. E. Smalley (1985). C60: Buckminsterfullerene. *Nature*, **318**(6042); 162–163

Kuhlmann, U., H. Jantoljak, N. Pfänder, P. Bernier, C. Journet, and C. Thomsen (1998). Infrared Active Phonons in Single-Walled Carbon Nanotubes. *Chemical Physics Letters*, **294**(1-3); 237–240

Kumar, A., S. Parveen, S. Husain, J. Ali, H. Harsh, and M. Husain (2013). Field Emission Behaviour of the Single Wall Carbon Nanotubes Grown by Plasma Enhanced Chemical Vapour Deposition (PECVD) System. *Journal of Nano-and Electronic Physics*, **5**(2); 02012–1

Kumar, A., S. Parveen, S. Husain, J. Ali, M. Zulfequar, and M. Husain (2014). A Comparative Study of Nitrogen Plasma Effect on Field Emission Characteristics of Single Wall Carbon Nanotubes Synthesized by Plasma Enhanced Chemical Vapor Deposition. *Applied Surface Science*, **322**; 236–241

Kuzmany, H., B. Burger, A. Thess, and R. E. Smalley (1998). Vibrational Spectra of Single Wall Carbon Nanotubes. *Carbon*, **36**(5-6); 709–712

Kuzmany, H., W. Plank, M. Hulman, C. Kramberger, A. Grüneis, T. Pichler, and Y. Achiba (2001). Determination of SWCNT Diameters from the Raman Response of the Radial Breathing Mode. *The European Physical Journal B–Condensed Matter and Complex Systems*, **22**; 307–320

Liu, L., Y. Qin, Z. X. Guo, and D. Zhu (2003). Reduction of Solubilized Multi-Walled Carbon Nanotubes. *Carbon*, **41**(2); 331–335

Liu, Z., S. M. Tabakman, Z. Chen, and H. Dai (2009). Preparation of Carbon Nanotube Bioconjugates for Biomedical Applications. *Nature Protocols*, **4**(9); 1372–1381

Lone, M. Y., A. Kumar, S. Husain, R. C. Singh, M. Zulfequar, and M. Husain (2019). Fabrication of Sensitive SWCNT Sensor for Trace Level Detection of Reducing and Oxidizing Gases (NH_3 and NO_2) at Room Temperature. *Physica E: Low-Dimensional Systems and Nanostructures*, **108**; 206–214

Lone, M. Y., A. Kumar, S. Husain, M. Zulfequar, and M. Husain (2017). Growth of Carbon Nanotubes by PECVD and Its Applications: A Review. *Current Nanoscience*, **13**(5); 536–546

Magrez, A., S. Kasas, V. Salicio, N. Pasquier, J. W. Seo, M. Celio, and L. Forró (2006). Cellular Toxicity of Carbon-Based Nanomaterials. *Nano Letters*, **6**(6); 1121–1125

Majzlíková, P., J. Sedláček, J. Prášek, J. Pekárek, V. Svatoš, A. G. Bannov, and J. Hubálek (2015). Sensing Properties of Multiwalled Carbon Nanotubes Grown in MW Plasma Torch: Electronic and Electrochemical Behavior, Gas Sensing, Field Emission, IR Absorption. *Sensors*, **15**(2); 2644–2661

Manohara, H. M., M. J. Bronikowski, M. Hoenk, B. D. Hunt, and P. H. Siegel (2005). High-Current-Density Field Emitters Based on Arrays of Carbon Nanotube Bundles. *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena*, **23**(1); 157–161

Mawhinney, D. B., V. Naumenko, A. Kuznetsova, J. T. J. Yates, J. Liu, and R. E. Smalley (2000). Surface Defect Site Density on Single Walled Carbon Nanotubes by Titration. *Chemical Physics Letters*, **324**(1-3); 213–216

Meng, J., J. Meng, J. Duan, H. Kong, L. Li, C. Wang, and X. D. Yang (2008). Carbon Nanotubes Conjugated to Tumor Lysate Protein Enhance the Efficacy of an Antitumor Immunotherapy. *Small*, **4**(9); 1364–1370

Morsi, M., M. Helal, M. El-Okr, and M. Ibrahim (2015). Preparation and Characterization of Multiwall Carbon Nanotubes Decorated with Zinc Oxide. *Der Pharma Chemica*, **7**(10); 139–144

Pai, P., K. Nair, S. Jamade, R. Shah, V. Ekshinge, and N. Jadhav (2006). Pharmaceutical Applications of Carbon Tubes and Nanohorns. *Current Pharma Research Journal*, **1**; 11–15

Paliwal, S., K. Pandey, S. Pawar, H. Joshi, and N. Bisht (2020). A Review on Carbon Nanotubes: As a Nano Carrier Drug Delivery System. *Indian Journal of Pharmaceutical Sciences*, **82**(5)

Paradise, M. and T. Goswami (2007). Carbon Nanotubes–Production and Industrial Applications. *Materials & Design*, **28**(5); 1477–1489

Peng, H., L. B. Alemany, J. L. Margrave, and V. N. Khabashesku (2003). Sidewall Carboxylic Acid Functionalization of Single-Walled Carbon Nanotubes. *Journal of the American Chemical Society*, **125**(49); 15174–15182

Pereira, M. F. R., J. L. Figueiredo, J. J. Órfão, P. Serp, P. Kalck, and Y. Kihn (2004). Catalytic Activity of Carbon Nanotubes in the Oxidative Dehydrogenation of Ethylbenzene. *Carbon*, **42**(14); 2807–2813

Pop, E., D. Mann, Q. Wang, K. Goodson, and H. Dai (2006). Thermal Conductance of an Individual Single-Wall Carbon Nanotube Above Room Temperature. *Nano Letters*, **6**(1); 96–100

Rahamathulla, M., R. R. Bhosale, R. A. Osmani, K. C. Mahima, A. P. Johnson, U. Hani, and H. V. Gangadharappa (2021). Carbon Nanotubes: Current Perspectives on Diverse Applications in Targeted Drug Delivery and Therapies. *Materials*, **14**(21); 6707

Raj, A. A. A. S., J. Ragavi, S. Rubila, D. Tirouthchelvamae, and T. V. Ranganathan (2013). Recent Trends in Nanotechnology Applications in Foods. *International Journal of Engineering Research and Technology (IJERT)*, **2**(10); 956–961

Rokade, P., A. Patil, R. Harshad, and S. Payghan (2021). Carbon Nanotubes: A Review. *International Journal of Creative Research Thoughts (IJCRT)*, **9**(8); 622–628

Rols, S., R. Almairac, L. Henrard, E. Anglaret, and J. L. Sauvajol (1999). Diffraction by Finite-Size Crystalline Bundles of Single Wall Nanotubes. *The European Physical Journal B–Condensed Matter and Complex Systems*, **10**; 263–270

Saito, T., K. Matsushige, and K. Tanaka (2002). Chemical Treatment and Modification of Multi-Walled Carbon Nanotubes. *Physica B: Condensed Matter*, **323**(1–4); 280–283

Sattler, K. D. (2010). *Handbook of Nanophysics: Principles and Methods*. CRC Press

Sayes, C. M., F. Liang, J. L. Hudson, J. Mendez, W. Guo, J. M. Beach, and V. L. Colvin (2006). Functionalization Density Dependence of Single-Walled Carbon Nanotubes Cytotoxicity In Vitro. *Toxicology Letters*, **161**(2); 135–142

Seidel, R., G. S. Duesberg, E. Unger, A. P. Graham, M. Liebau, and F. Kreupl (2004). Chemical Vapor Deposition Growth of Single-Walled Carbon Nanotubes at 600 °C and a Simple Growth Model. *The Journal of Physical Chemistry B*, **108**(6); 1888–1893

Sharma, S., S. Hussain, S. Singh, and S. S. Islam (2014). MWCNT-Conducting Polymer Composite Based Ammonia Gas Sensors: A New Approach for Complete Recovery Process. *Sensors and Actuators B: Chemical*, **194**; 213–219

Sinnott, S. B. and R. Andrews (2001). Carbon Nanotubes: Synthesis, Properties, and Applications. *Critical Reviews in Solid State and Materials Sciences*, **26**(3); 145–249

Sloan, J. and M. L. H. Green (2000). Encapsulation and Crystallization Behavior of Materials Inside Carbon Nanotubes. In *Handbook of Nanostructured Materials and Nanotechnology*. Academic Press, pages 407–432

Smart, S. K., A. I. Cassady, G. Q. Lu, and D. J. Martin (2006). The Biocompatibility of Carbon Nanotubes. *Carbon*, **44**(6); 1034–1047

Song, M. and D. Cai (2012). Graphene Functionalization: A Review. *Polymer-Graphene Nanocomposites*, **26**(26); 1–51

Taghdisi, S. M., P. Lavaee, M. Ramezani, and K. Abnous (2011). Reversible Targeting and Controlled Release Delivery of Daunorubicin to Cancer Cells by Aptamer-Wrapped Carbon Nanotubes. *European Journal of Pharmaceutics and Biopharmaceutics*, **77**(2); 200–206

Thurnherr, T., C. Brandenberger, K. Fischer, L. Diener, P. Manser, X. Maeder-Althaus, and P. Wick (2011). A Comparison of Acute and Long-Term Effects of Industrial Multiwalled Carbon Nanotubes on Human Lung and Immune Cells In Vitro. *Toxicology Letters*, **200**(3); 176–186

Varshney, K. (2014). Carbon Nanotubes: A Review on Synthesis, Properties and Applications. *International Journal of Engineering Research and General Science*, **2**(4); 660–677

Walker, P. L. J., J. F. Rakszawski, and G. R. Imperial (1959). Carbon Formation from Carbon Monoxide-Hydrogen Mixtures over Iron Catalysts. I. Properties of Carbon Formed. *The Journal of Physical Chemistry*, **63**(2); 133–140

Wang, S. J., W. X. Zhu, D. W. Liao, C. F. Ng, and C. T. Au (2004). In Situ FTIR Studies of NO Reduction over Carbon Nanotubes (CNTs) and 1 wt.% Pd/CNTs. *Catalysis Today*, **93**; 711–714

Wang, X., Z. Zhou, and F. Chen (2017). Surface Modification of Carbon Nanotubes with an Enhanced Antifungal Activity for the Control of Plant Fungal Pathogen. *Materials*, **10**(12); 1375

Wieckowski, S., G. Pastorin, M. Benincasa, C. Klumpp, J. P. Briand, R. Gennaro, and A. Bianco (2005). Targeted Delivery of Amphotericin B to Cells by Using Functionalized Carbon Nanotubes. *Angewandte Chemie International Edition*, **44**; 6358–6362

Xu, M., Q. Huang, Q. Chen, P. Guo, and Z. Sun (2003). Synthesis and Characterization of Octadecylamine Grafted Multi-Walled Carbon Nanotubes. *Chemical Physics Letters*, **375**(5-6); 598–604

Yang, Z. L., H. Z. Chen, L. Cao, H. Y. Li, and M. Wang (2004). Synthesis and Photoconductivity Study of Carbon Nanotube Bonded by Tetrasubstituted Amino Manganese Phthalocyanine. *Materials Science and Engineering: B*, **106**(1); 73–78

Ye, X. R., Y. Lin, C. Wang, M. H. Engelhard, Y. Wang, and C. M. Wai (2004). Supercritical Fluid Synthesis and Characterization of Catalytic Metal Nanoparticles on Carbon Nanotubes. *Journal of Materials Chemistry*, **14**(5); 908–913

Zare-Zardini, H., A. Amiri, M. Shanbedi, M. Memarpoor-Yazdi, and A. Asoodeh (2013). Studying of Antifungal Activity of Functionalized Multiwalled Carbon Nanotubes by Microwave-Assisted Technique. *Surface and Interface Analysis*, **45**(3); 751–755

Zeng, Q., Z. Li, and Y. Zhou (2009). Study on Catalytic Conversion of Methane to Acetylene in a Rotating Arc Reactor. *Journal of Natural Gas Chemistry*, **16**; 235–246

Zhou, M., Z. Wang, and X. Wang (2017). Carbon Nanotubes for Sensing Applications. In *Industrial Applications of Carbon Nanotubes*. Elsevier, pages 129–150

Zhu, W. Z., D. E. Miser, W. G. Chan, and M. R. Hajaligol (2003). Characterization of Multiwalled Carbon Nanotubes Prepared by Carbon Arc Cathode Deposit. *Materials Chemistry and Physics*, **82**(3); 638–647