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ORIGINAL

Biosynthesis of Carbon Nanoparticles and Their Potential Usefulness in Cancer Research and Biotechnology

Biosíntesis de nanopartículas de carbono y su potencial utilidad en la investigación del cáncer y la biotecnología

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ABSTRACT

The wrapped graphene sheets are used to create cylindrical Carbon Nanotubes (CNTs) which are carbon allotropes that have a nano-architecture. Graphene sheets are wrapped to create cylindrical carbon allotropes with a CNT nano-architecture. Considering the fascinating characteristics of CNTs has received a lot of interest from scientists throughout the years. Unique qualities such as the high degree of flexibility and the crucial length-to-diameter ratio with exceptional durability make it useful in many different applications. It is possible to modify the properties of CNTs by adjusting their distance, chirality, wall type, and time taken, which are dependent on the synthesis method. The numerous synthesis techniques for creating CNTs are in-depth discussed in this article. This study aims to investigate biosynthesis Carbon Nanoparticles (CNPs) with the eco-friendly methods and assess their use in biotechnology, including drug delivery, bioimaging, biosensing, etc. The review also includes descriptions of several characterization techniques. In addition, this study determines the principal or diverse biological synthesis approaches, physicochemical properties and functionalization methodologies of CNPs and their biocompatibility and prospects in biomedical and industrial applications. The use of CNTs in numerous technologically significant sectors is thoroughly covered. Finally, CNTs' potential features are discussed in light of their saleable use.

Keywords: Synthesis Routes; Biomedical Applications; Electronic Devices; Carbon Nanotubes (CNT); Energy Storage and Conversion.

RESUMEN

Las láminas de grafeno envueltas se utilizan para crear nanotubos de carbono cilíndricos (CNT), que son alótropos de carbono con una nanoarquitectura. Las láminas de grafeno se envuelven para crear alótropos de carbono cilíndricos con una nanoarquitectura de CNT. Las fascinantes características de los CNT han despertado gran interés entre los científicos a lo largo de los años. Sus cualidades únicas, como su alta flexibilidad y su crucial relación longitud-diámetro, junto con su excepcional durabilidad, los hacen útiles en diversas aplicaciones. Es posible modificar las propiedades de los CNT ajustando su distancia, quiralidad, tipo de pared y tiempo, que dependen del método de síntesis. En este artículo se analizan en profundidad las numerosas técnicas de síntesis para la creación de CNT. Este estudio tiene como objetivo investigar la biosíntesis de nanopartículas de carbono (CNP) con métodos ecológicos y evaluar su uso en biotecnología, incluyendo la administración de fármacos, la bioimagen, la biodetección, etc. La revisión también incluye descripciones de varias técnicas de caracterización. Además, este estudio determina los principales o diversos enfoques de síntesis biológica, las propiedades fisicoquímicas y las metodologías de funcionalización de los CNP, así como su biocompatibilidad y sus perspectivas en aplicaciones biomédicas e industriales. Se aborda en profundidad el uso de los CNT en numerosos sectores tecnológicamente significativos. Finalmente, se discuten las características potenciales de los CNT en vista de su uso comercial.

Palabras clave: Rutas de Síntesis; Aplicaciones Biomédicas; Dispositivos Electrónicos; Nanotubos de Carbono (CNT); Almacenamiento y Conversión de Energía.

INTRODUCTION

Carbon has now reached its peak in fullerenes and Carbon Nanotubes (CNTs), possibly the most promising of all nanomaterials, after more than a century of research. In physics, chemistry, and materials science are interested in CNTs due to their peculiar quasi-one-dimensional structure and their intriguing electrical properties along with mechanical properties.[1] It is becoming increasingly common to use CNTs in biology and medicine. The productivity and growth of plants have been studied using Carbon-based Nanomaterials (CNM).[2] Nanoparticles, nanobeads, fullerenes, nanodiamonds, nanodots, nanotubes, nanofibres, and nanohorns, are only a few of the many different types. Several types of Carbon Nanoparticles (CNPs) such as Multi-Walled CNT (MWCNT) and Single-Walled CNT (SWCNT) have been employed and investigated in plants. Both valuable and unfavorable properties of plant growth are caused by them.[3] The bonding in CNTs provides unique strength to the molecules, one of the major CNTs is represented in figure 1.

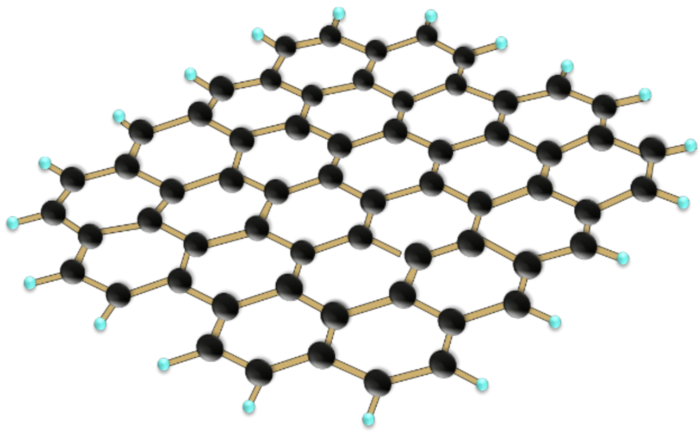

Figure 1. Structure of Graphene sheet

Nano Particles (NPs) are frequently distinct as substances employing at least one dimension between 1 and 100 nm. Both anthropogenic and natural sources can release them into the atmosphere. Engineered Nanoparticles (ENPs) have newly emerged among anthropogenic nanoparticles and have demonstrated substantial growth.[4] CNPs, an innovative category of quasi-spherical carbon-based nanotechnology, with dimensions of less than 10 nm. With its powerful photoluminescence that changes with size and stimulation wavelengths, CNPs have increased a lot of importance as novel flaming particles in fields where size, charge, solubility in water, accessibility, and compatibility alongside the labels are important considerations.[5,6] The higher the centrifugation rpm, the CNPs' fluorescence characteristics improve. Centrifugation at 1000 rpm is used to gather the CNPs, which exhibit the maximum quantum yield.[7] By using this separation technique, it can synthesize extremely luminous CNPs on a milligram scale.[8] Particularly, finding affordable and simple methods for the mass manufacture of highly luminous carbon nano-particles still represents a significant difficulty.[9] The graphene, CNT, and carbon quantum dots (CQD), which have been successfully used in biology, healthcare, and broadly conceived environmental applications, are given special attention.[10]

Study provided advice for the appropriate usage of CNPs in agricultural applications and compared their impacts on plant development and soil quality improvement.[11] The production of colloidal suspensions of CNPs adorned with Copper Oxide (CuO) NPs in a liquid (PLAL) medium using the Pulsed Laser Ablation technology.[12] By adjusting the emulsion polarity, study created Mesoporous Carbon NanoParticles (MCNP), which were designed to modify the large mesopore size, particle diameter, and surface roughness all at once.[13] The preparation

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procedures and possible uses of nano-fluids in wastewater treatment, hazardous gas removal processes, and microbe control mechanisms for environmental remediation were covered.(14) Flexo electrically oriented aromatics are known to possess an essential part in the production of carbon nanoparticles, as demonstrated in the study.(15) The initial medically allowed carbon nanoparticle, Carbon Nanoparticle Suspension Injection (CNPSI), was a ground-breaking nano-radioprotective medication utilized for effective intestinal radioprotection.(16) The use of FNPs in nanomedicine, especially for applications involving drug delivery and sensing that require FNPs to react to both internal and outer stimuli like temperature, light, magnetic fields, enzymes, redox, pH, and enzymes.(17) Study demonstrated that water-soluble CNPs have a strong germination-promoting effect on seeds without harming seedling growth.(18) The study assessed harmfulness of several kinds of carbon black nanomaterials given at the start of embryogenesis in an embryo perfect.(19)

METHOD

The study intends to address the latest developments in CNT functionality, providing researchers with a worldwide perspective on the key CNT functioning techniques in biotechnological nanomaterials. The study focuses on the eco-friendly methods used in biosynthesis of CNPs and their use in biotechnology applications such as drug delivery, bioimaging, and biosensing. Despite the numerous publications on CNTs, the study purposes to provide a comprehensive understanding of these nanostructures. This section examines various methods for synthesizing CNTs with desirable qualities for particular uses, with an emphasis on those that yield fewer architectural and chemical flaws, offering a description of each.

Synthesis of CNTs

Arc discharge method

Figure 2 depicts the finding of CNTs via arc plasma vaporization of pure graphite rods. The apparatus comprises a space containing two carbon rods disappeared carbon molecules, and metallic substances like nickel, cobalt, or iron.(20) The vessel is compressed and warmed to around 4000 K (17), with approximately partial of the dissolved carbon solidifying on the cathode edge. An accumulation occurs at a degree of 1 mm/min as the anode's metal is exhausted.

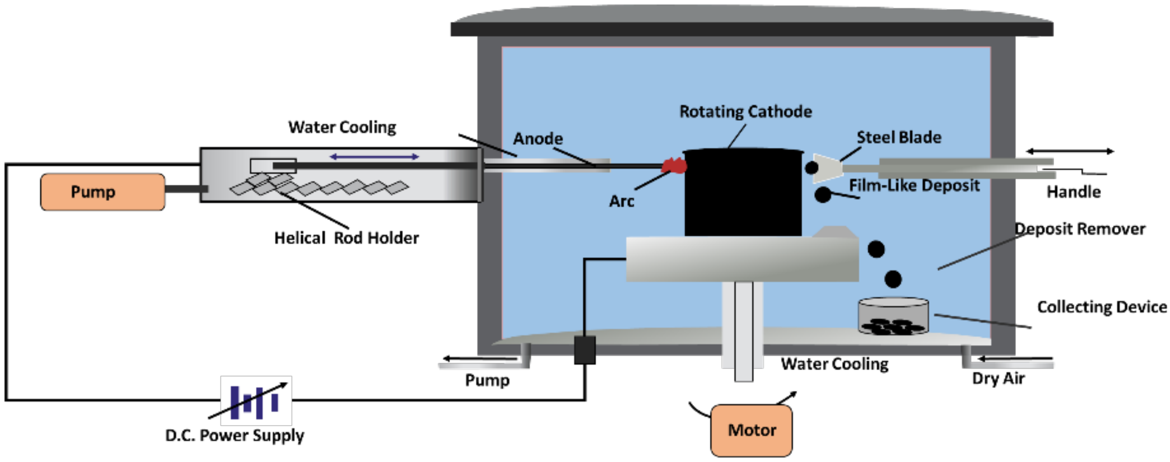

Figure 2. Structure of Arc discharge

Arc discharge production of CNTs incorporates two significant techniques: employing different catalyst precursors or not using any catalyst precursors. MWCNTs can be produced without the need for catalyst precursors, whereas SWCNTs require a variety of catalyst progenitors as well as an elaborate anode composed of graphite and metal.(21) It suggests the probability of large nanotube production, but it uses higher temperatures, resulting in fewer structural defects and fewer regulators over the position of the nanotubes. Additionally, the metal catalyst required for the response necessitates product purification due to the metallic catalyst needed.

Laser ablation

A laser vaporizes a graphite target in an inert atmosphere, causing carbon molecules to be transported to a powered by water copper collectors, as shown in figure 3. The temperature at which these goods react determines their quality and yield. A small quantity of transition metal is added to the carbon mark, resulting in the formation of small-walled carbon nanotubes (SWCNTs).(22) Variations in the intensity of the laser, propagation temperatures, catalyst substance, gaseous, and pressure can all affect the standard nanotube length and dispersion.(23) Maximum influence, radiation fluidity, oscillation wavelengths, and the rate of recurrence are all laser-related parameters that influence CNT manufacture.

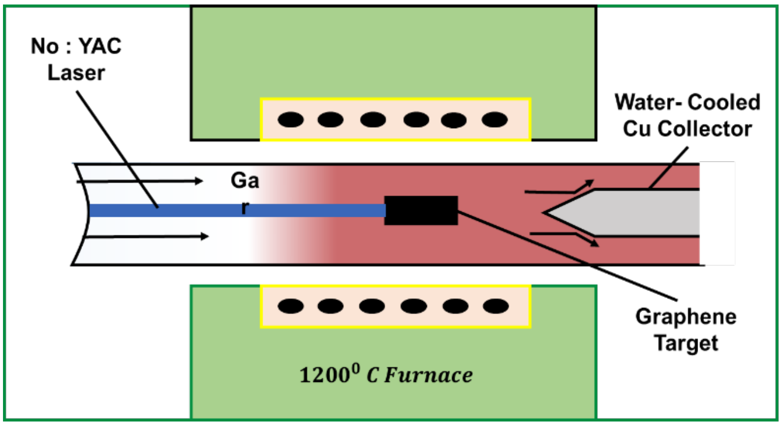

Figure 3. Architecture of laser ablation method

As the evaporated components cool, tiny graphite molecules and atoms condense into greater clusters, possibly containing fullers.[24] The stimulants also consolidate and bind to graphite groups. The technique offers superior yield and short metal layers, but its foremost weakness is the lack of uniformity in the obtained nanotubes and the high laser power required due to the use of high-purity graphite rods.

Chemical Vapor Deposition (CVD)

CVD is an actual strategy for producing CNTs on the surfaces of catalytic nanoparticles.[25] The two most significant CVD techniques are thermal CVD and discharge-enhanced CVD; however, alternative methods such as oxygen-assisted and water-assisted CVD, electromagnetic hemoglobin, radio regularity CVD, and heated filamentous CVD are also accessible, as illustrated in Figure 4. CNTs can be manufactured at ambient temperatures, and their dimensions can be adjusted through variation in the diameters of the catalysts nanoparticles. This approach generates a high number of CNTs by combining an inorganic carbon supply with a resistively heated coil that can serve as an energy generator.[26]

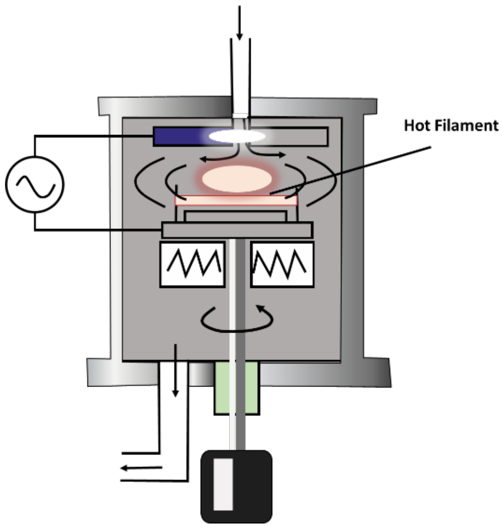

Figure 4. Structure of CVD Systems

CVD is a two-step procedure for synthesizing CNTs. The first step involves preparing a catalyst through a physical gas statement, spattering, or dip covering. The substrate is then heated in a carbon-rich vaporous atmosphere.[27] The synthesis temperature ranges from 500-1000 °C. CVD is a cost-effective approach for enormous, pure CNT manufacturing that provides excellent purification as well as simple management of its response pathway as compared to laser ablation.

Nebulized spray pyrolysis method

To create MWCNTs with homogeneous dimensions in oriented packages, this approach employs a nebulized spray generated by a specific ultrasound evaporator. Ferrocene and ethanol are sprayed into a tubular heater at 800 °C with an oxygen circulation rate of 1 L/min. Ethanol is employed because it is ecologically friendly, inexpensive, produces harmful substances, and is easy to handle. MWCNTs can develop rapidly on surfaces.[28] The benefit of employing a compressed spray is that it is easily scaled to an industrial-scale technique.

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Flame synthesis method

Flame synthesis is a scalable, continuous-flow procedure for producing nanotubes, especially when metallic transitions such as Fe or Ni are used. This approach has distinguishing traits not present in other synthetic techniques, such as low retention durations for catalyst inception and nanotube development.[29] Gases like C2H2, C2H4, CH4, C2H6, and CO, in the post flame area are abundant carbon sources. The exothermic process which is powered by the chemical power generated in the flames, necessitates the use of catalysis to supply reaction locations for substantial black carbon deposits.

Silane solution method

CNTs are formed utilizing the silane solution technique, which involves immersing a substrate, such as Papers made of carbon or aluminum meshes, in a metallic catalyst an approach preferred Co: Ni, and inserting an energy source, such as ethene, through the substratum, with the catalyst dropped on it, while the substratum is elevated.[30,31]

Methods for cnt classification

The classification process for CNTs based on their structures, functionalities, and synthetic criteria. Researchers are analyzing the functionalization differences between single-walled SWCNTs and MWCNTs to determine their suitability for heavy metal adsorption, energy storage, and biomedicine applications, as well as their optimal performance for specific environmental or industrial applications.[32]

Spectroscopic using Raman

The Raman study is an efficient, straightforward, non-intrusive, and non-destructive characterization method. Most user communities have access to the devices, and it is possible to utilize them at the surrounding pressure and temperature. For analyzing modifications in the characteristics of nanotubes manufactured under various techniques and environments, this method is incredibly sensitive. The collection's high Raman signal intensities allow for comprehensive and accurate electrical and structural assessment as a function of incident laser power. The C atom's radial vibrations are associated with the Radial Breathing Mode (RBM). These characteristics make CNTs unique. The presence of SWCNTs or MWCNTs in a particular carbon material can therefore be determined using RBM frequency. equation (1) can be used to determine the dimensions of CNTs in the presence of RBM modes.

$$RBM = {}^{A}/_{dt} + B \qquad (1)$$

Here A and B are empirically determined variables. The resonance Raman intensity I_{RBM} can be used to study the electrical framework. The main factor affecting I_{RBM} is the electronic states that are accessible for optical conversions. The above G-band frequencies and overtones with grouping mode are unusual dispersal impacts that make it broad and insufficiently strong to be distinguished from the background noise. But these combination modes and overtones can be readily shown in SWCNTs for double resonant occurrences and the appearance of van Hove singularity.

Frameworks of cnts

CNTs can be created in a variety of morphologies, including waved, straight, coiled, branching, beaded, and regularly bending architectures. MWCNTs with a square shape are generated parallel to the substrate on porous silicon substrates. With the right combination of external forces, it is possible to create consistently bent CNTs using a DC plasma-enhanced CVD process.[33] CNTs regularly bend when the electric field lines' axes are reversed. These CNTs are advised for usage in systems with nano-circuit interrelationships mechanical nano-springs, and high-resolution AFM tips. The bending can be caused by two topological pentagon-heptagon flaws or interior mechanical distortion under light bending force, which can be caused by the weight of the nanotube itself, an inadequate growing atmosphere, or interaction with neighboring nanotubes. Beads can have polycrystalline or amorphous graphite and derived in a variability of shapes. It appears as an outcome of the degradation of the beading step and the rise in the viscous carbon on the nanotube surfaces.[34]

Transmission Electron Microscopy (TEM)

The TEM is a system for investigating the thin samples that reflect an image into the sample as electrons pass through its contents. TEM and the standard light microscope are similar in many ways. The diameter of a single CNT and the diameters of a group of CNT can be measured by TEM imaging. Each DWCNT is at least 1,5 nm in size, and SWCNT bundles can have diameters as tiny as 3 nm. Through the use of high-magnification TEM images, the distance between edges in different bundles can be statistically determined.

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Microscopy using Atomic Force

Among the current microscope methods, Atomic Force Microscopy (AFM) is the one that is employed the most frequently for characterizing materials. The AFM is widely used because of its affordability and speed in producing topographic three-dimensional samples with atomic resolution. Relevant information for the surface's structural research can be found in the AFM data. It can measure the total length of the nanotube and the dimensions of the bundles with the use of this technology.

Applications of cnts

Based on their outstanding performance, applications of CNTs can bring about several advantages for the environment and human health. Outstanding mechanical, electrical, optical, thermal, and chemical properties are found in CNTs. Before CNT, the diamond is the best-known thermal conductor. CNTs have thermal conductivities that are at least twice as high as those of diamonds. The sp2 carbon-carbon connection gives the CNTs exceptional mechanical strength. The most powerful nanotubes for a variety of applications have a 1000 GPa Young's modulus, which is roughly five times that of steel.

Storage and conversion of energy

Since they are efficient solar absorbers and heat transfer fluids, Carbon Nanofluids (CNF) are commonly used in solar thermal conversion. Therminol 55 treated with potassium persulfate caused MWCNT performance to decrease much more quickly than untreated TH 55, suggesting that K-MWCNTs-TH 55 soak up sunlight more competently than TH 55.[35] Direct Absorption Solar Collectors (DASCs) have recently drawn interest in the use of stable CNT fluids. Si, Si@C, and Si@C-CNT performance are evaluated. After 40 cycles, the Silicon (Si) electrode in figure 5 exhibits poor cycling performance. Si that has been coated with carbon has noticeably improved cycle stability. The Si nanoparticles' homogeneous layer of carbon, which regulates volumetric variations improve conductivity, and results in ability preservation of 48 % after 40 cycles, is responsible for this stability. The reversible capacity of the carbon-coated Si-CNT composite (Si@C-CNTs) shows lower gain for the first five cycles but thereafter started to decline. The Si@C-CNTs anode surpasses its two anodes in terms of cycling stability, maintaining 70 % of its capacity after 40 cycles. Figure 5, Si@C delivers the highest initial capacity (~3000 mAh g^{-1}), but degrades over cycles while Si drops below 500 mAh g^{-1} relatively rapid. Si@C-CNTs shows the best stability while providing a reasonable tradeoff between capacity and durability occur to more conductive materials and increased structural integrity. Si@C-CNTs is an attractive battery material design.

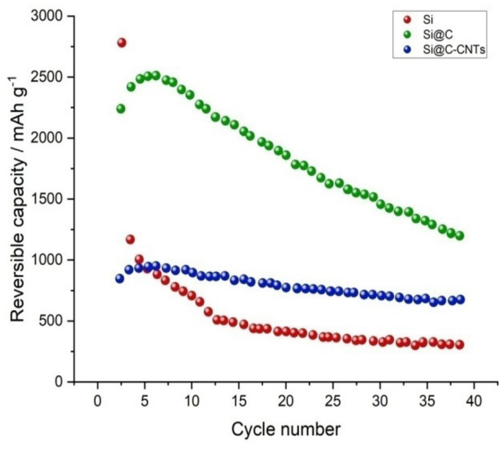

Figure 5. Si, Si@C, and Si@C-CNT performance

The findings suggest that Si@C has the greatest initial capacity but suffers gradual decline throughout cycling, whereas Si@C-CNTs experiences a more consistent cycling performance due to better mechanical and electrical properties compared to its Si@C and CNT nanostructured complements. The CNTs improve battery performance by mitigating capacity fade and improving conductivity, but some degradation does occur when cycling, suggesting further improvements determined to be necessary for long-term cycling stability.

Table 1 displays the adsorption of heavy metals onto several CNT types. To assess the Procion Red MX-5B dye's ability to bind to CNTs in various industrial wastes. Exceptional adsorption ability of COOH-functionalized MWCNTs based on their huge surface area, appropriate pore configuration, and combined abundance of a range of surface functional groups. The functionalized CNTs' different chemical sorption sites improve the metal ion and dye attraction.

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Table 1. Heavy metal ion components with various kinds of CNT		
Components	**Ionic Metals**	**Capability of Adsorption (mg/g−1)**
CNT	Pb^{2+}	26,33
CNT–CONH	Hg^{2+}	2,747
CNT–COO−	Hg^{2+}	2,999
CNTs HNO_3)	Pb^{2+}	49,95
CNT–COO−	Cd^{2+}	3,325
MWCNTs	Ni^{2+}	6,62
CNT–OH	Cu^{2+}	1,342
MWCNTsHNO_3)	Pb^{2+}	89,99

It represents the adsorption potentials of different types of CNTs for heavy metal ions, emphasizing their efficiencies in the removal of toxic metals from nature. It compares the enhancement of metal ion adsorption ability of functionalized and treated CNTs. Table 1 shows that MWCNTs (HNO_3) has the highest Pb^{2+} adsorption (89,99 mg/g) and CNT–OH has the lowest Cu^{2+} adsorption (1,342 mg/g). Acid-treated CNTs yield a total improvement in removal of metals. Various functional groups can have dramatically increased adsorption efficiencies for Hg^{2+} and Cd^2. It's critical to choose the optimized CNT type for water purification and heavy metal removal applications.

Functionalization process

Raw CNTs feature hydrophilic exteriors that are insoluble in water-soluble solutions. Functioning is an organic production technique that provides required functional groups to CNT walls, yielding Functionalized Carbon Nanotubes (F-CNT). There are two approaches: covalent and noncovalent bonding.

Covalent Bonding

A nanotube generates strong chemical bonds with connected molecules as a consequence of polymeric sequences' covalent bonding to CNTs. Moving procedures comprise the spreading of polymerization from surface-derived initiates on CNTs or the insertion of prefabricated polymer chains.[36] There are three main methods for by covalent molecules to carbon nanotubes: flawless prefunctionalized, and oxidized. Oxidation of CNTs is a common modification using oxidizing agents like concentrated nitric acid. Both methods involve functioning interactions on the CNT surfaces. Carboxyl sets emerge at the ends of nanotubes and cracks on the sidewalls of CNTs. Common methods for producing COOH on CNT sidewalls include nitrene cyclic addition, arylation with diazonium salts, and 1,3-dipolar cycloaddition.

The curvature of CNTs strains sp2 hybridized carbon atoms, making pure CNTs sensitive to addition processes such as the Bingel process. Covalent bonding allows for stable adhesion in bioenvironments. Providing hydrophilic plastics, such as Polyethylene Glycol (PEG), to oxidation CNTs produces CNT-polymer combinations. Covalently PEGylated SWCNTs are used both in culture and in real-world situations. However, covalent bonding reduces CNTs' intrinsic physical features, including photoluminescence and Raman scattering.

As an outcome, a covalent connection is unable to be utilized to integrate CNTs for photothermal or thermal purposes. Various covalent functionalization procedures have been utilized to alter CNTs for a variety of applications.[37] Covalent bonding integration includes linking desired groups to tubes and changing carbon atom hybridization from sp2 to sp3. MWCNTs were double-covalently functionalized by connecting hydrophobic cyclodextrin units and branched polyethylene. Functioning of SWNTs via atom- Transfers radicals' additions in metals (I/II) redox complexes enables a covalent connection of carboxylic and aryl groups. The covalent functionalization of 5-10- 15-20-tetra porphyrinatonickel (II) (NiTAP) with MWCNTs via an amide linkage demonstrates the metallic ion replacement increases the issue point in Raman and is dependent on the technique of acylation.

Non-Covalent Bonding

Noncovalent bonding of particles to CNTs is the most extensively employed technique of medication administration. Nanotechnology can be accomplished by coating CNTs with amphiphilic surfactant polymers, resulting in micelle-like nanostructures where amphiphilic substances are covered. Another popular functionalization is p-p bonding, which is accomplished by arranging pyrene receptors on the CNT surfaces. This association can also be utilized on individual strands of DNA but is unstable and cleaved by nucleases, making its biological applications limited.[38] Noncovalent coupling maintains CNTs' characteristics, except length reduction, and shows tremendous promise for imaging and photothermal ablation. The noncovalent technique incorporates chemicals' moiety Physical Solubility on nanotubes graphitic interfaces through assembling communications and polymer covering apparatuses. The microemulsion approach modifies the external building of MWCNTs by adding an extremity consisting of that can be combined with real-time hydrolysis.

Through to produce OH-MWCNT. Micro-emulsion modification enhances the hydrophobic characteristics of MWCNTs while maintaining their motorized and electrical properties. The Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Photoelectron Spectroscopy (XPS) analyses confirmed the attachments as depicted in figure 6.

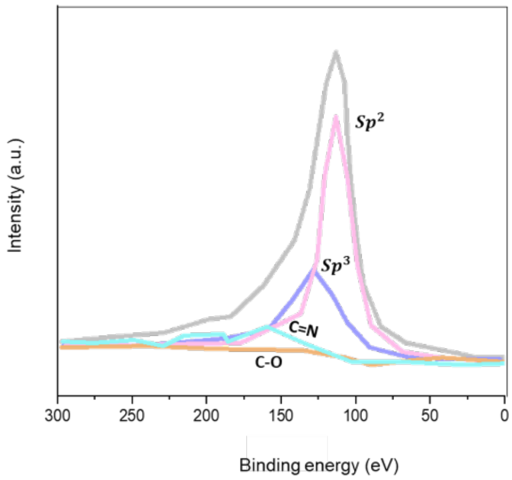

Figure 6. Graphical outcome of FTIR and XPS spectroscopies

It can be rapidly and effectively solvent-free noncovalently functioning with three distinct amines. The substance with the greatest amine content was identified in octadecyl amine, while the lowest has been identified in 1,5-diaminonaphthalene. This approach addresses the main problem in functionalizing MWCNTs. Functionalized MWCNT properties were investigated by preparing water polyurethane composites. Functioning MWCNTs showed better interaction with WPU macromolecules, which resulted in enhanced physical properties, hydrophilicity, and transfer of electricity. Carboxyl groups on the surface of CNTs can be exploited to create amino-functionalized CNTs via an oxidation process. The molecular study of these compounds demonstrates the covalent grafting of amine nitrogen to CNTs. MWCNTs are functionalized via amidation, which involves adding carboxylic (COOH) and amine (N-H) groups to their external tubes. FTIR research demonstrated the existence of -COOH carboxylic acid and amid groups. SEM pictures of SWCNT-CONH2 and SWCNT-COOH revealed a thin layer of organic compounds (amide) on the surface, which increased the nanotube dimension comparable to the SWCNT architecture. FT-IR spectroscopy and SEM images were utilized to discover intriguing chemical interaction reactions and investigate surface structure in generated materials.

CONCLUSIONS

This study explored the biosynthesis of CNPs using environmentally safe and inexpensive strategies, which offer numerous benefits over traditional synthetic methods. The biosynthesis of CNPs can reduce environmental waste and increase their use in biomedical imaging, biosensing, and tissue engineering, thereby reducing waste. There has been more to learn about CNT, and there has the room to advance the usage of CNTs in a variety of sectors. The results of CNT synthesis, functionalization, and design have had a considerable impact on possible advancements in several disciplines. To generate CNTs for the planned uses, advancements in the synthesis processes were needed. For instance, the size of the catalyst affects the diameter of CNTs produced by CVD. Numerous studies could be done to discover more effective techniques to create catalyst particles that are precisely uniform in size, enabling the manufacturing of SWCNTs with a specific diameter. The CNTs were more expensive than other nano-carbon materials. To bring down the cost of CNTs to a reasonable level, efforts could be undertaken to find new carbon sources that were affordable and abundant. SWCNTs' peculiar features could be used to create an electronic component with nanometer-scale dimensions. With the extreme productive potential and applications, scientists determined the specific methods to utilize them. Metal filaments, which burned out quickly in X-ray machines could eventually be replaced by CNTs. The mobile X-ray technology used in ambulances, customs, and airport security could benefit from the technology. CNTs are certainly important for many commercial applications, but they can be necessary for energy storage and conversion. Researchers want to develop molecule-based, atomically tiny circuits. The use of SWCNTs' peculiar features could result in nanometer-sized electrical devices. With the extreme productive potential and applications, scientists were focused on the specific methods to employ it. In the future, CNTs could take place in the X-ray equipment's metal filaments that are quickly addressed.

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CONFLICT OF INTEREST
Authors declare that there is no conflict of interest.

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