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Chemistry

A REVIEW ON CARBON NANOTUBES: PREPARATION, PROPERTIES & APPLICATIONS: CARBON NANOTUBES

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ABSTRACT The term "nanotechnology" emerged in 1947, paving the way for its development, including the discovery of carbon nanotubes (CNTs) in 1991. CNTs are cylindrical structures made of carbon atoms arranged in a hexagonal pattern. They're incredibly small, about one billionth of a meter, yet incredibly strong, with unique properties compared to bulk materials. The eye-catching features of carbon nanotubes are their electronic, mechanical, optical and chemical characteristics. The most common techniques used nowadays are: arc discharge, laser ablation and chemical vapor deposition. Different case study on fibrous materials, Human health in detail. In this review article, the applications of CNTs in various technologically important fields are discussed in detail.

KEYWORDS : SWCNT's, MWCNT's, Pulmonary fibrosis, Cancer.

INTRODUCTION

The word nanotechnology was used first time in 1947 by Prof.Nano's of Tokyo Science University while explaining silicon machine from this development of nanotechnology begin [9].Then in 1991 Prof.Sumio Iijima invented the Carbon nanotubes , he not only took pictures of them but he put together them and explain special properties of nanotubes [1].These are allotropes of carbon made up with cylindrical nanostructure consisting of major of graphite sheet [12].The structure of carbon nanotubes is formed by a layer of carbon atom that are bound together in hexagonal pattern [3,12].As this nanotubes have reduction of size as 10^-9 times or one thousand times smaller than a micron . As a billionth of a meter as equivalent to 10 Å. As this is 10000 times smaller than human hair [13].As this one atom of thick layer of carbon is called as graphene which having sp2 hybridization which stronger than sp3 hybridization as present in diamond as mean this sp2 >sp3 so, the graphene is stronger than the diamond & it is 100 times stronger than steel & They are only $1/6^{th}$ the weight of steel having high aspect ratio it enhances filler material [4]so, we use this material for alternative for material use in many different industries like as coming generation of computers , wireless technology , making light weight body of cars , stretchable material [3] , Cancer cells tracing[11] , Tissue engineering[10] , Artificial implant scopes[10], Biomedical field [12].

Classification Of Carbon Nanotubes:

Single Walled Carbon Nanotubes (SWCNT's)

The single walled carbon Nanotubes (SWCNT's) made up of a single layer of graphene sheets. As this CNT's are called as one-dimensional structure becomes its ratio of length to diameter is greater than 1000. As this having different physical & chemical properties [9]. This was discovered by Iijima And Ichihashi in 1993 by various types of synthesis process using intermetallic catalyst at 1000-degree Celsius.

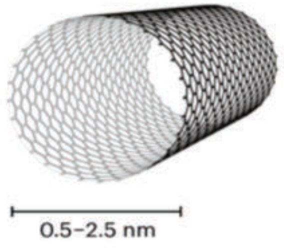

Figure 1. Single Walled Carbon Nanotubes

Multi Walled Carbon Nanotubes (MWCNT's)

The multiwalled carbon nanotubes (MWCNT's) are made up of multi-layer of graphene sheets. As layer multi walled carbon nanotubes have contains number of concentric layers & separated by a layer of 3.3 Å. As length and diameter of this vary too much from SWCNT's and also properties vary but as we see that DWCNT's (Double Walled Carbon Nanotubes) has much of the similar properties as compared to SWCNT. The DWCNT's was discovered by falhaut et al in 2003 by the means of chemical vapor deposition techniques from reduction of methane & hydrogen [9].

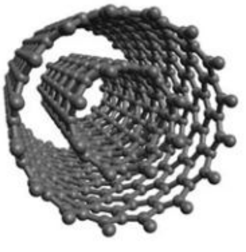

Figure 2. Double Walled CNT

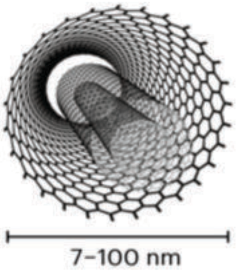

Figure 3. Multi Walled CNT

Characteristics:

The carbon nanotubes (CNT's) they have extraordinary structural, mechanical, and electrical properties that derive from the special properties of carbon bonds, their unique quasi-one-dimensional nature, and their cylindrical symmetry [17].

Mechanical Properties:

As mechanical properties of carbon nanotubes discuss their elastic properties and strain-induced transformations but this property is applicable to only single walled nanotubes because it having less defects and are much strong. As we focus on two aspects as elastic deformations, where the shape of the nanotube may change but the local atomic coordination does not and the onset of irreversible behavior, where the atomic structure undergoes irreversible changes [17,16]. They can reversibly bend to very high angles, and their tensile strength is unmatched by any known material [11,10,17]. The specific heat of MWNTs from 10 to 300 K [18]. The sp2 carbon-carbon bonding CNTs show high mechanical strength [18]. Young's modulus value of the nanotubes has 1000 GPa, (approximately six times higher than that of steel), are considered as the best for a variety of applications.

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Electrical Properties:

The carbon nanotubes are one-dimensional structure so, they show remarkable electrical properties. As nanomaterials have lower thermal and electrical conductivity than bulk materials [10].This nanotubes have approximately zero resistance because there is no collision between electron in wire to flow & nanotubes is as size of electron only [11].The classical free electron theory of metal states that movement of electron within a metallic solid lead to electrical conductivity. As nanomaterial have a high-density grain boundary which make electrical-phonon and phenon-phenon scattering effective and reduce conductivity [21].

Method Of Synthesis Carbon Nanotubes:

There are various techniques have been employed for the successful production of carbon nanotubes (CNT) such as laser ablation, arc discharge, chemical vapor deposition, high-pressure carbon monoxide disproportionation (using catalyst using iron oxide/mixture of cobalt and molybdenum), electrolysis, flame synthesis, pyrolysis and more [7]. As disparity between them we classified them in between major two category as Physical & Chemical method of synthesis carbon nanotubes (CNT's).

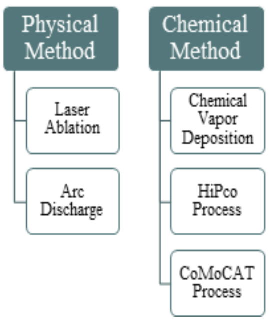

Figure 4. Disparity between Method of synthesis of CNT's

Physical Method:

As shown in Fig 4, the physical techniques are laser ablation, arc discharge method. This process is very high temperature process & simple mechanism.

Laser ablation:

The laser ablation method is also called as physical vapor deposition (PVD). As in this technique by which a material can be vaporized into gaseous form and then deposited on the surface of a substrate [10]. A graphite target is vaporized by a laser in an argon-filled chamber at 1200°C. Carbon atoms are carried by argon gas to a cooled copper collector, where they grow into CNTs. For multi-walled CNTs, continuous or pulsed lasers are used. Single-walled CNTs require catalyst nanoparticles like Fe, Co, Ni. The resulting CNTs are purified for purity [9,7].

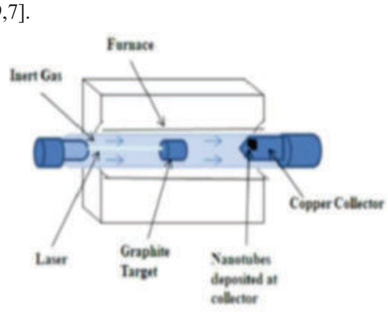

Figure 5. Laser Ablation Method

Arc Discharge:

In 1992, Ebbesen and Ajayan from NEC Japan discovered [9] a method involving two graphite rods placed a few millimeters apart. Passing around 100 Amp current through them yields 30% to 90% CNT formation [9,7]. Short tubes of SWCNT with diameters of 0.6 to 1.4 nm and MSCNTs with inner diameters of 1-3 nm and outer diameters of around 10 nm are produced. The method easily yields SWCNTs and MWCNTs but may create some structural defects. MWCNTs are produced without catalyst, and open-air synthesis is possible. While MWCNTs don't require a catalyst, SWCNTs need catalysts like platinum group metals (Ru, Rh, Pd, Os, Ir, Pt) and others (Fe, Co, Ni, f/Ni, La, Ce) [7].

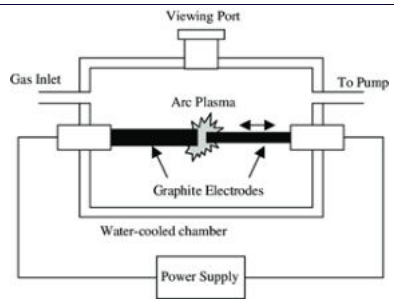

Figure 6. Arc Discharge Method

Chemical Method

As shown in Fig 4, the chemical techniques are chemical vapor deposition method, HiPco, CoMoCAT process in this react chemically and forms a nanomaterial product that is deposited on the substrate.

Chemical vapor deposition method

CNTs are synthesized using thermal chemical vapor deposition (CVD) where a hydrocarbon gas serves as the carbon source. A quartz tube in a high-temperature furnace (500-900°C) contains a substrate with catalyst nanoparticles, placed in an inert gas atmosphere like argon. Hydrocarbon gas is pumped in, undergoing pyrolysis to form vapor carbon atoms [10]. These atoms bind on the substrate, growing as multi-walled carbon nanotubes (MWCNTs) through Vander Waal forces. For single-walled carbon nanotubes, Fe, Co, Ni catalyst nanoparticles are used. The resulting CNTs are purified for purity [7,11].

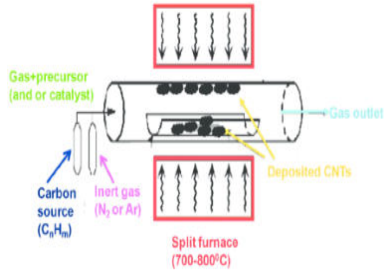

Figure 7. Chemical vapor deposition method

Applications Of Carbon Nanotubes

Potential Application of CNTs in Vacuum Microelectronics

Field emission is a quantum effect where high electric fields allow electrons near the Fermi level to escape. It's used in applications like displays, electron microscopes, and amplifiers, needing low threshold fields and high stability. Lowering the threshold field requires materials with low work function and high field enhancement factor. Some materials for this purpose include carbon nanotubes, diamond, tungsten, molybdenum, and silicon, with various threshold fields [22].

Drug delivery with carbon nanotubes

Developing effective drug delivery systems is a critical research area. These systems aim to enhance the therapeutic potential of drugs. Functionalized carbon nanotubes (f-CNT) have the potential to serve as carriers for delivering small drug molecules, but their use in delivering anticancer, antibacterial, or antiviral agents is still being explored. In another approach, single-walled carbon nanohorns, similar to CNT, were used for drug delivery. They successfully loaded and released dexamethasone, maintaining its biological activity. These findings suggest that f-CNT could be promising drug delivery systems for various mammalian cells. However, further research is needed to understand their metabolism, distribution, and clearance from the body for future development [23].

Carbon Nanotubes in Cancer Treatment

Carbon nanotubes (CNTs) have been extensively researched for drug delivery in cancer therapy due to their large surface area and cell membrane-penetrating capabilities. They are commonly used to conjugate chemotherapeutic drugs like doxorubicin, improving drug delivery efficiency and reducing systemic toxicity. Additionally, CNTs are employed in combination with photo-thermal therapy, enhancing drug release and targeting cancer cells. Natural compounds such as curcumin can also be delivered using CNTs. Furthermore, CNT-based theranostic platforms offer the potential for both cancer detection and treatment, including non-invasive imaging and targeted drug delivery [24].

Tissue Generation

Recent advancements in cell and organ transplantation, along with developments in carbon nanotube (CNT) chemistry, have significantly contributed to the progress of CNT-based tissue engineering and regenerative medicine. CNTs stand out as a promising material for tissue scaffolds due to their biocompatibility, resistance to biodegradation, and the ability to enhance organ regeneration through biomolecule functionalization [24]. They can reinforce scaffold strength and conductivity when incorporated into the body. Researchers have successfully used CNTs in composite materials with polymers or collagen for tissue regeneration. CNTs also find applications in cell tracking, sensing cellular behavior, and improving tissue matrices, such as enhancing bone tissue regeneration in mice and promoting neurogenic cell differentiation in vitro [25].

Detection of Toxic Proteins

Carbon nanotubes (CNTs) show promise as drug delivery vehicles but raise concerns about organ toxicity. They enter cells via endocytosis, causing oxidative stress, inflammation, and cytotoxicity due to free radical generation. Accumulation in organs like spleen, kidneys, and lungs amplifies oxidative stress, leading to reactive oxygen species (ROS) formation, apoptosis, genetic damage, and enzyme inactivation. Inflammation results from macrophages' inability to engulf CNTs, and CNT exposure can induce granuloma formation, potentially causing chronic granulomatous diseases[26].

As Bone Substitutes

CNTs, with their exceptional tensile strength, can serve as bone substitutes and implants when infused with calcium and fashioned to mimic the bone's structure [27-28].

Preserve of Drugs

Carbon nanotubes possess inherent antioxidant properties, making them suitable for preserving drugs prone to oxidation. They can shield these sensitive drugs from degradation, enhancing their stability and shelf life [29].

Gene Therapy

Carbon nanotubes are employed in gene therapy for DNA delivery, a technique that aims to treat harmful genetic diseases by introducing corrective DNA into cells. This allows for the potential correction or replacement of faulty genes, offering a promising approach to combat genetic disorders [30-31].

Genetic Engineering

In genetic engineering, carbon nanotubes and carbon nanohorns are utilized to manipulate genes and atoms, enabling advancements in bioimaging, genomics, proteomics, and tissue engineering. These nanomaterials play a pivotal role in developing innovative techniques and applications for understanding and modifying biological systems at the molecular level [32].

Cancer Cell Identification

Nanodevices are advancing cancer treatment, detection, and diagnosis. Nanostructures, smaller than 100 nm, can enter cells and interact with DNA and proteins. Castillo et al. improved the detection of cervical cancer cells with a peptide nanotube-folic acid graphene electrode, targeting folate receptors [33-35].

Other

Carbon nanotubes has application in vast fields like as High-strength composites[37], Nanoprobes and sensors[37], Actuators [38] , Energy storage and conversion devices, Electronic devices[41], Hydrogen storage media,Catalysis [42].

Drawbacks Of Carbon Nanotubes

The nanotechnology is costly compare to other technology in now days and also hard to maintain high quality and lower impurities as well acumen manpower needed[39].The huge amount of energy is required to produce CNT's by**.** Laser ablation method & Arc discharge method[40].

Case Study On Carbon Nanotubes
Prioritize Production Over Precaution

As the burgeoning demand for Carbon Nanotubes (CNTs) surged, the prominence of financial gains and innovative prospects took precedence, often overshadowing apprehensions regarding human health and environmental impacts. This era witnessed a substantial proliferation in both the number of scientific publications and patents dedicated to CNTs. The critical role of governmental support, particularly in the United States and Japan, cannot be understated in fostering the advancement of CNT research[42].

By 2008, an array of consumer products, inclusive of sports equipment, commenced integrating CNTs. Corporations adroitly employed CNTs as a means to exemplify their technological prowess. Notably, sports equipment like tennis racquets and bicycle components emerged as early adopters of CNTs, touting their superior attributes of robustness and lightweight construction[43].

Predominantly, the commercial realm for CNT-infused products revolves around sporting equipment, although alternative applications encompass armor and the construction of petite aircraft frames. CNTs function as reinforcing agents within these materials, imparting strength, reduced weight, and enhanced performance[44].

Furthermore, numerous CNT-based products are approaching commercial viability, showing immense potential in diverse fields such as targeted drug delivery for cancer treatment, the development of CNT-based solar cells, the construction of lighter and sturdier wind turbine blades, and the provision of potable water through CNT water filters that effectively eliminate microbial and chemical contaminants. Nevertheless, it remains imperative to ensure that the realization of these advantages does not occur at the expense of human well-being and ecological integrity[43-44].

Regrettably, despite the exponential growth in CNT production, there has been a conspicuous lack of emphasis on strategies aimed at mitigating the potential adverse environmental and health repercussions. Although the cost of CNTs has experienced a substantial reduction, thereby stimulating their commercial adoption, funding allocated for research pertaining to environmental and health safety concerns has remained insufficient, given the magnitude of potential risks[45].

Since 2006, the global production capacity of CNTs has witnessed a remarkable tenfold increase. Nevertheless, challenges persist in terms of producing pure Single-Walled CNTs (SWCNTs) at a cost-effective price point. The prices of SWCNTs are projected to experience a downward trajectory as the demand for these materials surges, accompanied by continued advancements in manufacturing techniques[46].

Documentation of Adverse Health Impacts on Humans

When Carbon Nanotubes (CNTs) burst onto the scene, they wowed everyone with their incredible mechanical, thermal, and electrical properties. What made them stand out were their unique physical and chemical characteristics, like their size, shape, surface area, surface chemistry, and reactivity. But scientists were well aware that these attributes could potentially spell trouble when it came to their effects on our health.

Even before they started studying the dangers of CNTs, scientists had some ideas based on what we already knew about the toxicology of fibers and particles. In simpler terms, they could see trouble coming because CNTs had some features that made them look risky from a health perspective[47].

Pulmonary fibrosis

Until the mid-2000s, there was a glaring lack of research on how Carbon Nanotubes (CNTs) might affect the environment and human health. It wasn't until 2004 that scientists at NASA conducted one of the first studies. They found that when mice were exposed to Single-Walled CNTs (SWCNTs), their lungs showed signs of inflammation and damage. They did this by basically squirting the CNTs directly into the mouse lungs, a standard method for testing the impact of dust on the lungs[54].

Other studies that followed observed similar issues in other animals and noted the development of "progressive fibrosis," which is basically scarring deep in the lungs. What's important is that these early studies compared the toxicity of SWCNTs with other materials like carbon black and quartz, which are known to be harmful to the lungs. And the results indicated that SWCNTs were even more toxic[55].

Now, when it comes to Multi-Walled CNTs (MWCNTs), they were found to cause similar problems as SWCNTs. Animals exposed to MWCNTs for a short time developed severe and ongoing lung scarring. What's particularly concerning is that this occurred at levels of exposure similar to what some workers might experience in their jobs. However, it seems that SWCNTs might be even more potent at causing lung scarring than MWCNTs[57].

But what is "pulmonary fibrosis"? It's a serious and irreversible lung disease that has historically been linked to exposure to things like silica and asbestos. It happens when particles get stuck in the deep parts of the lung, damaging the cells that try to clear them. This damage leads to scarring or fibrosis. Pulmonary fibrosis is a progressive disease, which means the damage can continue even after the exposure stops. If someone is heavily and consistently exposed, the outlook can be pretty bleak, possibly leading to heart problems due to a lack of oxygen in the blood[56].

Now, it's important to note that we don't yet know for sure if people working with CNTs experience these effects. Research into the health of workers exposed to CNTs is still in the early stages[57].

Cancer

The potential risks associated with Carbon Nanotubes (CNTs) didn't catch much attention in the broader public health community until the word "cancer" entered the conversation.

In 2008, two studies involving lab animals exposed to Multi-Walled CNTs (MWCNTs) raised concerns about mesothelioma, a type of cancer that affects the lining of the lungs and abdomen. Mesothelioma is primarily linked to exposure to asbestos fibers. These studies found that when long MWCNTs (those over 10 micrometers in length) were injected into the lining of the abdomen in mice, they caused inflammation and lesions that are considered precursors to asbestos-related mesothelioma in humans. More studies supported these findings, showing that the extent of inflammation was related to the length of the fibers. These studies strongly suggest that CNTs could potentially cause mesothelioma in animals and, by extension, in humans[58].

Since 2008, additional research has confirmed that long straight MWCNTs could indeed lead to cancer. Recent studies have shown that after being inhaled, these materials can migrate to the lining of the lungs, where mesothelioma develops. Additionally, some studies observed MWCNTs penetrating the lining of the pleura, which is part of how mesothelioma can develop. These effects have included DNA damage, abnormal cell growth, and the formation of tumors in the lining of the lungs[59].

Single-Walled CNTs (SWCNTs) have also been found to migrate to the lining of the lungs, but they have not shown the same ability to penetrate the lining, likely because they are less rigid than MWCNTs, which have multiple layers of carbon. Nevertheless, research has shown that SWCNTs can enter the nuclei of airway cells and disrupt normal cell division, potentially leading to genetic abnormalities.

Researchers at the US National Institute for Occupational Safety and Health (NIOSH) reported that chronic inhalation of MWCNTs by mice increased the incidence of lung tumors. This is significant because asbestos is a known cause of both lung cancer and mesothelioma. The study revealed that MWCNTs have the potential to promote the development and growth of lung tumors when mice are first exposed to a chemical that initiates the disease. However, further studies are needed to determine whether CNTs can also initiate the disease themselves[60].

Comprehensive Effects: Widespread Inflammation and Impact on Heart, Reproduction, and Growth

Animal studies have delved into the health consequences of exposure to Carbon Nanotubes (CNTs) beyond just lung issues, albeit to a lesser extent. These studies have mainly focused on the impact of CNTs on the cardiovascular system and systemic inflammation, which is anticipated based on the hazards associated with exposure to larger particles, like fine particles found in air pollution[64].

When animals have been exposed to Single-Walled CNTs (SWCNTs), it has triggered broader responses throughout their bodies. This includes sparking systemic inflammation and affecting the cardiovascular system. Toxicological research indicates that exposure to SWCNTs can result in increased levels of inflammatory substances in the blood, oxidative stress in the aorta (a large blood vessel), and markers linked to the development of artery-clogging plaque, which is characteristic of atherosclerosis. Studies involving Multi-Walled CNTs (MWCNTs) have also noticed reduced responsiveness of small coronary arteries to substances that normally make them dilate, which can have implications for heart health[61-62].

In contrast, there have been relatively few studies examining the potential effects of CNTs on development and reproduction. Yet, a couple of recent toxicological studies found concerning outcomes from exposure to different SWCNTs, including fetal death, elevated levels of harmful reactive molecules in the placenta and offspring, and birth defects, particularly skeletal abnormalities. These effects haven't been as pronounced in studies involving MWCNTs[63].

Properties of Substances and Their Impact on Human Health

One of the studies from 2008, which was among the first to highlight a possible connection between Carbon Nanotubes (CNTs) and mesothelioma, made a noteworthy discovery: the size and shape of CNTs significantly affect their biological impact. It was observed that when mice were exposed to Multi-Walled CNTs (MWCNTs) that were long and straight, they developed precancerous growths. However, if mice were exposed to MWCNTs that were tightly coiled together, no adverse effects were observed—no lesions, no inflammation[65].

So, why does size and shape matter when it comes to toxicity? Our body's immune system typically gets rid of foreign substances using immune cells called macrophages. These cells engulf the material and eliminate it through various immune responses. It has been widely suggested in the research community that small or coiled MWCNTs can be cleared by the immune system. In contrast, long and rigid MWCNTs, which are larger than macrophages, cannot be fully engulfed and removed. This inability to completely engulf the material leads to the release of compounds that damage surrounding cells, resulting in inflammation, lesions, and progressive scarring, known as fibrosis[66].

Long and rigid MWCNTs can inflict a "double hit" on the pulmonary system. These CNTs have a high aspect ratio, meaning they are narrow but quite long (in the nanometers diameter but micrometers in length). They are also highly bio persistent, meaning they do not break down and remain in the lungs if not removed by the immune system. This combination of a high aspect ratio and bio persistence contributes to their inherent hazard. These characteristics are already understood because they are shared with asbestos fibers[67].

Furthermore, longer MWCNTs are more biologically active when they come into contact with cells, leading to more significant inflammatory and fibrotic effects. While research suggests that short MWCNTs are generally cleared by the lungs, there is evidence that short MWCNTs can be retained after brief exposures and move to the pleural cavity of the lung. In this cavity, clearance may be restricted, meaning even short MWCNTs may cause harm. Some researchers have proposed a cutoff length of 5 μm as a threshold for considering MWCNTs pathogenic.

The surface and chemical composition of CNTs also play a crucial role in their biological effects. Depending on the manufacturing process, CNTs may contain various catalysts and contaminants like cobalt, iron, nickel, and molybdenum, which are known to be toxic because they are highly reactive and biologically active. These metals can trigger the release of reactive oxygen species from macrophages, causing oxidative stress. Structural defects on the CNT surface, such as those introduced by grinding MWCNTs, can increase pulmonary toxicity[68].

In comparison to other particles, CNTs tend to have larger surface areas. This is significant because if a CNT contains soluble or reactive material, its greater surface area results in a higher effective dose of the compound. CNTs are being explored for their drug delivery potential due to their high surface area and small size, which could efficiently transport chemotherapy drugs to tumor sites. However, these same characteristics can also lead to toxic effects.

Furthermore, the surface chemistry of CNTs can be intentionally altered to suit their intended commercial applications. CNTs can be coated or "functionalized" with specific chemicals to enhance their electrical, mechanical, or chemical properties. Unfortunately, designers of these products often do not consider how altering the surface chemistry of CNTs might influence their toxicity[68-69].

Assessing Environmental Impact: Uncovering the Consequences

As Carbon Nanotubes (CNTs) production increases and they become more prevalent in industrial and commercial products, it's evident that their release into the environment is on the rise. CNTs can enter the environment at various stages, from manufacturing and use to recycling and disposal. Just like the scarcity of data on their health effects, there's limited information on how CNTs behave in the environment, their fate, and their impact on ecosystems. Most of the available literature on this topic didn't emerge until the late 2000s and is still relatively new.

While ongoing research is needed, the studies conducted thus far have raised concerns about the environmental effects of CNTs, particularly among certain aquatic species and microorganisms. Similar to research on human health, the environmental studies reveal certain characteristics of CNTs that can predict potential environmental problems. These include the increased availability of toxic substances and the possibility of bioaccumulation[70].

For many terrestrial organisms, ecotoxicity studies generally show minimal evidence of toxicity. However, some aquatic organisms seem to be particularly sensitive to CNT exposure. This includes lower pelagic organisms like algae, freshwater fleas (daphnids), and certain fish species. Studies have shown that both Single-Walled CNTs (SWCNTs) and Multi-Walled CNTs (MWCNTs) with various properties can inhibit the growth of freshwater and marine algae. For example, studies on freshwater fleas found that ingested CNTs can disrupt their food intake and movement at low concentrations and become more toxic with longer exposures. Parameters such as impaired growth and reproduction were affected at even lower concentrations for both SWCNTs and MWCNTs. Studies on juvenile rainbow trout demonstrated that exposure to SWCNTs in water caused systemic toxicity, including respiratory issues, neurological problems, and liver toxicity, even at extremely low concentrations, which are considered "extremely toxic to aquatic life."

SWCNTs are known for their strong antimicrobial properties, causing bacterial cell death upon contact. While most SWCNTs tested demonstrate antimicrobial activity, the level of toxicity varies with factors like size, shape, and chemical composition. For instance, the higher the metal content and the longer the CNT, the more toxic they are to bacteria. MWCNTs also have antibacterial properties but tend to be less toxic to bacteria than SWCNTs. Some research is exploring how to apply the antimicrobial properties of SWCNTs in commercial applications. However, the release of SWCNTs into the environment could have troublesome implications, particularly in processes like wastewater treatment that rely on microbial activity[71].

Can Carbon Nanotubes (CNTs) Be Both Safe and Environmentally Friendly: A Reality Check?

In essence, recent findings regarding the potential health and environmental consequences of Carbon Nanotubes (CNTs) validate early concerns about their potential for harm. Moreover, it's becoming clear that not all CNTs are created equal, and some are safer than others. This complexity raises significant questions about whether policies and practices can or should differentiate between various types of CNTs[70].

Is it feasible to produce only coiled or bundled CNTs without chemical impurities? Can we treat them with additional chemical functional groups to minimize potential toxic effects? Is it possible to manufacture or use them only in tightly controlled settings? Even if we manage to address these questions, can we guarantee that these same CNTs won't have adverse effects in aquatic ecosystems, given the immense complexity of those environments, both biologically and chemically?

Furthermore, can we ensure that CNTs are not released into sewage systems, where they could disrupt the microbial processes that enable the safe treatment of water before it's discharged into our rivers, lakes, and oceans? Is it viable to develop and utilize only the safest CNTs for specific applications? These questions pose significant challenges and require careful consideration as we navigate the complex landscape of CNTs' safety and environmental impact[71-73].

Sustainable and Environmentally Friendly Nanotechnology

There is a growing interest in the field of "green" nanotechnology, which is all about advancing sustainability through the proactive design, manufacturing, and application of nanomaterials. Researchers, particularly at institutions like the Safer Nanomaterials and Nanomanufacturing Initiative and the Center for Green Chemistry and Green Engineering, are pioneering this concept, supported by organizations like the Sustainable Nanotechnology Organization. Their mission is to demonstrate that nanomaterials can play a pivotal role in promoting sustainability, benefiting society, the environment, and human health while minimizing any adverse impacts.

This hopeful approach is rooted in the potential of nanotubes (CNTs) to bring about significant social advantages, such as breakthroughs in medicine, enhanced efficiency in renewable energy generation, and the provision of safe drinking water, among countless other possibilities. CNTs, with their exceptional mechanical, thermal, and electrical properties, can even serve as substitutes for various known toxic chemicals[74].

Green nanotechnology bridges two critical disciplines: green chemistry and green engineering. It challenges the traditional mindset of chemists and engineers, who often think about the health, safety, and environmental concerns of their creations as an afterthought. In contrast, green chemists and engineers consider these factors as inherent properties of the chemicals and materials they work with, treating hazard as a design attribute to be addressed from the outset. Their goal is the elimination of hazard, guaranteeing prevention of disease and environmental harm.

While the promise of green nanotechnology is technically sound, the development of truly green CNT products remains an ongoing challenge. Overcoming barriers involves the need for engineers and chemists with training in green engineering and chemistry and the establishment of clear design rules for CNTs and other nanomaterials. A roadmap for green nanotechnology, which includes principles like SAFER (see Table 2), offers a blueprint for safer nanotechnology design. These principles encompass aspects such as modifying material characteristics to reduce hazards, considering alternative materials, and enclosing nanomaterials within less hazardous compounds[75].

This ongoing effort aims to advance green nanotechnology and ensure that it fulfills its potential in creating sustainable, safe, and environmentally friendly solutions.

CONCLUSION:

Nanotechnology, particularly carbon nanotubes (CNTs), has opened up a world of possibilities due to their unique properties. They are incredibly strong and conductive, making them valuable in industries like electronics, medicine, and materials science. CNTs can be synthesized through physical and chemical methods. Their applications range from drug delivery and cancer treatment to tissue regeneration and gene therapy. We has seen case study of different application of CNT's as fibrous material, treatment on cancer , impact on heath of human and animals, Impact on abiotic factors of environment. They also find use in various fields like composites, sensors, and energy storage. Overall, CNTs have transformed numerous industries and hold immense potential for future innovations.

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