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Organic and Inorganic Nanomaterials: A Mini Review

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Abstract

Nanomaterials have a wide range of applications in various fields due to their unique properties such as high surface area to volume ratio, stability, inertness, ease of functionalization, and novel optical, electrical, and magnetic behaviour. Common types include nanotubes, dendrimers, quantum dots, and fullerenes. This review focused on the science and applications of inorganic and organic nanomaterials, emphasising their synthesis, processing, characterization, and applications in various fields, with the goal of providing useful insights to aid future development of efficient and commercially viable technology for large-scale production. Nanomaterials were also discussed for imaging, cell and gene delivery, biosensors, cancer treatment, therapy, and other uses.

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Introduction

Nanoparticles, both organic and inorganic, are materials having two or more dimensions and a size between one and one hundred nanometers. Nanoparticles have distinct physical and chemical features that are size dependant, such as optical, magnetic, catalytic, thermodynamic, and electrochemical capabilities. Nanoparticles' unique properties are also influenced by their chemical composition and shape. Organic polymers (organic nanoparticles) and/or inorganic elements are used to make nanoparticles (inorganic nanoparticles). Organic nanoparticles include liposomes, dendrimers, carbon nanomaterials, and polymeric mielies.

Liposomes are phospholipid vesicles (50-100 nm) with an interior aqueous phase and a bilayer membrane structure comparable to biological membranes. Liposomes are classed as multi-, oligo-, or uni-lamellar based on their size and number of layers. Liposomes' amphiphilic nature allows them to carry both hydrophilic and hydrophobic medicines that are entrapped within their aqueous interior. Liposomes have high circulation, penetration, and diffusion properties due to their physicochemical properties. Furthermore, ligands and/or polymers can be added to the liposome surface to improve drug delivery selectivity.

Dendrimers are highly branched synthetic polymers (less than 15 nm) having layered topologies that include a central core, an internal area, and multiple terminal groups that govern dendrimer properties. A dendrimer can be made utilising a variety of chemical techniques, the nature of which determines the solubility and biological activity of the dendrimer. Dendrimers are employed as tissue-repair scaffolds because they have intrinsic drug characteristics. Furthermore, due to chemical alteration of their numerous terminal groups, dendrimers are effective medication and imaging diagnosis-agent carriers.

Carbon nanotubes are made up of coaxial graphite sheets (100 nm) folded up into cylinders and belong to the fullerene family. These nanotubes can be single-walled (one graphite sheet) or multi-walled (many graphite sheets) (several concentric graphite sheets). They are strong, have good electrical qualities, and are good heat conductors. Nanotubes are frequently utilised as biosensors due to their metallic or semiconductor characteristics. Surface functionalisation can make carbon nanotubes water soluble. As a result, they're also used as medication transporters and scaffolds for tissue repair. Inorganic nanoparticles with a central core made of inorganic materials, such as quantum dots, polystyrene, magnetic, ceramic, and metallic nanoparticles, exhibit fluorescent, magnetic, electrical, and optical capabilities.

Quantum dots are nanocrystals of colloidal fluorescent semiconductors (2-10 nm). The centre core of quantum dots is made up of elements from the periodic system's groups II-VI (CdSe, CdTe, Cds, PbSe, ZnS, and ZnSe) or III-V (GaAs, GaN, InP, and InAs) that are 'overcoated' with a layer of ZnS. Photostability is a property of quantum dots. They have emission spectra that can be tuned by size and composition, as well as a high quantum yield. Photobleaching resistance is excellent, as is resistance to photo and chemical deterioration. Quantum dots are ideal contrast agents for imaging and bioassay labels because of all of these features [1].

Applications of Organic and Inorganic Nanomaterials

Magnetic nanoparticles (mNPs)

Magnetic nanoparticles are one of the most important inorganic nanomaterials (mNPs). A magnetic core (e.g. magnetite (Fe3O4) or maghemite (g-Fe2O3)) is generally present [2,3]. Other metals, such as cobalt and nickel, are also employed, although their applications

are limited due to their toxicity and oxidation vulnerability [4]. Iron is essential in almost all biological tissues, yet it has a low bioavailability. It can be harmful to cells in the form of free iron or when it is not coupled with haemoglobin in some situations [2].

MRI: MRI is a powerful imaging method that offers the advantage of high spatial resolution of contrast differences between tissues due to its noninvasive nature and capabilities of giving high 3-D resolution and tomographic. Due to their strong magnetic moment, mNP-based contrast agents provide superior image enhancement as well as improved cellular uptake and slower clearance from the target site as compared to typical gadolinium chelates [5]. The use of iron oxide mNPs as MRI signal enhancers has been approved by the US Food and Drug Administration [2].

Hyperthermia: Temperature-sensitive cells have a higher rate of tumour cell proliferation than other healthy cells. Intracellular hyperthermia is a strategy for treating malignancies that has been developed using mNPs (specifically SPIOs) [6]. This treatment comprises of a delivery agent that functions as a nanoscale heater, causing the cell to heat up and necrosis to occur [7,8].

Magnetic transfection: When nucleic acid delivery is controlled by a magnetic field acting on nucleic acid vectors attached to mNPs, the term "magnetic transfection" is employed. Both 'big' nucleic acids and tiny constructs can be transfected via magnetic transfection [9]. These mNPs are designed to bind negatively charged DNAs to the mNPs via electrostatic interactions, with the DNAs being released after cell internalisation [10].

Gold and silver nanoparticles

Because of its versatility as an indicator and detection probe, colloidal gold or gold nanoparticles (AuNPs) may be easily manufactured for use in a variety of applications. While most of the attractive qualities of AuNPs in terms of bioapplications are shared with other NPs (e.g. size, inertness, ease of synthesis, and biocompatibility), AuNPs are particularly attractive candidates for biological imaging techniques because they can be visualised based on the interaction of the NPs and light, in which the particles strongly absorb and scatter visible light [11].

Biological imaging: For decades, AuNPs have been used as a contrast agent in electron microscopy. Colloidal gold particles are electron dense due to the high atomic number of gold, making them ideal for electron microscopy. AuNPs, on the other hand, have been used in a number of other imaging techniques that rely on the plasmon band [12].

Cell delivery vehicles: Most delivery tactics for magnetic and other forms of NPs are relatively similar, such as utilising cancer-targeting moieties conjugated to NPs for transport into cancer tissue. For many years, gold has been utilised to carry chemicals into cells. AuNPs are used in delivery applications because of their tiny size, colloidal stability, ease of synthesis and conjugation, and biocompatibility. Gene guns, for example, can be used to force the introduction of genes into cells, or cellular absorption can be achieved [2].

Biosensor: While the methods used in imaging and distribution are mostly passive, AuNPs play a more active role in plasmon-related sensing. In essence, the NPs must be able to detect the presence of analyte molecules and produce a concentration reading. Changes in the optical characteristics of AuNPs are commonly used to accomplish this. The plasmon resonance frequency, which can be exploited for sensing, is a very dependable intrinsic property of AuNPs [13].

Quantum dots

QDs are colloidal nanometer-sized crystals made composed of atoms from the periodic table's groups II to VI (e.g. Cd, Zn, Se, Te) or III to V (e.g. In, P, As) [14]. The most common QDs used in bioapplications were made of CdSe and wrapped in a ZnS shell to protect them from the highly poisonous cadmium. The energy bandgap of absorption spectra can be altered from ultraviolet to near-infrared (NIR) region by trapping electrons in various sizes [15].

Biological imaging: QDs appeared to be a very attractive probe for longer-term investigations in living cells due to their great photostability and low cytotoxicity, if a few limitations were addressed. Water solubility is a crucial need for in vitro and in vivo imaging at first. Generally, thiol groups (SH) are linked to the ZnS shell with a terminal carboxyl (COOH) to boost the hydrophilicity of QDs, which leads to cell internalisation [16].

Single-cell imaging: Single-cell tracking was first developed to explore membrane receptor dynamics. The earliest experiments used micrometer-sized AuNP beads to study transmembrane protein diffusion [17]. Similar experiments employing QDs to target membrane proteins and analyse the mobility and kinetics of receptors, transmembrane proteins, and synapses have recently been published [18].

In vivo imaging: The first QD-peptide conjugates to target tumour vasculature in mice were employed in vivo [2]. The tissue-specific peptide coating on (CdSe) Frontiers of Nanoscience ZnS QDs boosted NP accumulation at vascular locations after intravascular injection, according to histology [19]. This study highlighted the potential of employing QDs for molecular-level detection, albeit it does not address QD imaging in a living animal.

Targeted therapies: QDs are used as delivery and reporter systems in the same way as mNPs are used in transfection therapy in vivo. When compared to other types of delivery vehicles, NP transfection has the advantage of being able to be functionalized with a variety of oligonucleotides and cell-binding ligands at the same time, potentially allowing multiple gene knockdowns and higher affinity for the target cell at the same time. One siRNA per particle in combination with >15 peptides, or two siRNA per particle in combination with 10 peptides, provided excellent knockdown and targeting, according to studies [20].

Carbon nanotubes

Hollow and porous NPs, such as nanotubes, nanoshells, and hollow spheres, can hold a lot of cargo, which improves signal and sensitivity. Carbon nanotubes are graphene sheets that are cylindrical in shape. Although most carbon nanotube applications have been focused on microelectronic devices, because to their unique electronic and physical properties, carbon nanotubes have shown some promising properties for biological applications, such as facile translocation through cell membranes and low toxicity [21].

Neuronal tissue engineering: CNTs are quickly gaining traction as a technology platform for building new neuroimplantable devices. They have a unique combination of strength and flexibility, as well as physical and chemical qualities that enable them to efficiently conduct electrical current in electrochemical interfaces. CNTs can thus be used in tissue engineering scaffolds in the form of fibres or tubes with sizes similar to those found in neural processes like axons and dendrites [22]. MWCNTs were used to generate rat brain neurons in the first

application of nanotubes in neuroscience research [23].

Imaging and cancer treatment: SWCNTs have been used in the thermal necrosis of cancer cells in the same way that mNPs and AuNPs have. In xenografted mice, intratumoural injection of tubes combined with NIR irradiation resulted in thermal death of human epidermoid oral carcinoma KB tumour cells with minimal side effects up to 6 months after treatment, with elimination via urine in three months.

Conclusion

Nanomaterials have a wide range of industrial, biological, and electronic uses due to their incredibly small feature size. Because of their huge specific surface area and strong reactivity, they make excellent adsorbents, catalysts, and sensors. NPs play a crucial role in many biotechnology applications, and in the next years, they are expected to take centre stage in a slew of new and emerging applications. Biomedical applications such as better drug delivery to tumour cells and the use of dendrimers for regenerative medicine, as well as fields such as water purification and disinfection, food manufacturing, and packaging, are all exciting future possibilities. Finding a simple, efficient, and controllable approach to mass produce nanomaterials as well as bridge their applications in optoelectronics will be appealing.

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