

Nanocages: Unlocking the Potential of Molecular Enclosures

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Description

Nanotechnology has revolutionized various fields, enabling scientists and engineers to manipulate matter at the nanoscale level. Among the remarkable advancements in this domain, nanocages have emerged as fascinating structures with immense potential in diverse scientific and technological applications. These molecular enclosures, resembling microscopic cages, exhibit unique properties that make them a subject of extensive research and exploration. At their core, nanocages are three-dimensional structures constructed from nanoscale building blocks, typically composed of atoms or molecules. Their defining characteristic lies in their hollow interior, which can encapsulate guest molecules or ions, offering a protected and controlled environment for various processes. Nanocages can be fabricated using different techniques, including self-assembly, templating, and chemical synthesis, allowing for the customization of their size, shape, and chemical composition to suit specific applications. The concept of nanocages originated from the desire to mimic natural systems, such as viruses and proteins, which possess hollow cavities capable of encapsulating specific molecules. These biological counterparts inspired scientists to design synthetic counterparts that replicate their functionalities while offering additional advantages. Nanocages can be tailored to exhibit specific properties, including selective encapsulation, controlled release, and targeted delivery, making them versatile tools in drug delivery, catalysis, sensing, and energy storage, among others. In the realm of drug delivery, nanocages offer a promising solution for targeted therapy. By encapsulating therapeutic molecules within their cavities, nanocages can protect them from degradation and enhance their stability. Furthermore, their surface can be modified to selectively recognize and bind to specific targets, such as cancer cells. This targeted delivery approach minimizes off-target effects and maximizes the therapeutic efficacy, revolutionizing the treatment of various diseases.

Design and Synthesis of Nanocages

Nanocages also play a vital role in catalysis, where they act as miniature reactors, confining reactant molecules within their interior. This confinement effect enhances reaction rates and selectivity by providing a controlled environment that promotes specific chemical transformations. Additionally, the ability to

tune the size and composition of nanocages allows researchers to optimize catalytic performance, making them highly efficient catalysts for a wide range of reactions, including hydrogenation, oxidation, and carbon dioxide conversion. Sensing is another area where nanocages excel. By selectively encapsulating target molecules, nanocages can act as highly sensitive and specific sensors. Changes in the encapsulated molecules' properties, such as fluorescence or electrical conductivity, can be detected, providing a means for detecting and quantifying analytes with high precision. This has significant implications in environmental monitoring, medical diagnostics, and food safety, where rapid and accurate detection methods are paramount. Energy storage is yet another realm where nanocages have made notable contributions. Nanocages with tailored structures and chemical compositions can serve as ideal hosts for storing and releasing energy carriers, such as hydrogen, methane, and even ions in advanced batteries. By encapsulating these energy carriers, nanocages offer enhanced storage capacity, stability, and safety compared to conventional methods. This paves the way for the development of efficient and sustainable energy storage systems that can power various applications, including electric vehicles and renewable energy grids. The journey of nanocages, however, is not without challenges. Fabrication methods need to be refined to ensure reproducibility, scalability, and cost-effectiveness. The structural integrity of nanocages should be optimized to withstand harsh conditions and maintain their functionality. Furthermore, understanding the dynamics of guest molecules within the nanocages is essential for precise control over their release, particularly in drug delivery applications. Additionally, safety considerations must be addressed to ensure the biocompatibility and long-term effects of nanocages on living organisms. Nevertheless, the rapid progress in nanotechnology and interdisciplinary collaborations have propelled nanocages. In the vast realm of nanotechnology, researchers and scientists continuously strive to develop novel materials and structures that push the boundaries of what is possible at the atomic and molecular level. Among these remarkable innovations, nanocages have emerged as a fascinating class of structures with enormous potential in various fields, ranging from medicine and drug delivery to catalysis and energy storage. Nanocages, as the name suggests, are tiny structures that resemble cages or hollow containers on a nanoscale, capable of encapsulating and manipulating molecules within their confined spaces. This article explores the captivating world of nanocages, shedding light on their design, synthesis

methods, and remarkable applications. Nanocages exhibit diverse shapes and structures, including polyhedral, spherical, tubular, and helical forms. These structures are typically composed of inorganic or organic building blocks, carefully arranged to create the desired cage-like architecture.

Applications of Nanocages

The selection of building blocks and their arrangement depends on the specific requirements of the intended application. Inorganic nanocages are often constructed using metal ions or clusters, such as gold, silver, platinum, or palladium, which serve as the core framework. These metallic cores are then surrounded by ligands or organic molecules, forming a protective shell that defines the cage's shape and size. The ligands can be tailored to have specific binding affinities towards target molecules, enabling selective encapsulation and release. Organic nanocages, on the other hand, are primarily formed through self-assembly processes driven by non-covalent interactions, such as hydrogen bonding, π - π stacking, or hydrophobic interactions. These self-assembled nanocages can be designed with precise control over their size, shape, and internal cavities, allowing for the accommodation of various guest molecules. Synthesis methods for nanocages include template-assisted synthesis, sol-gel methods, coordination chemistry, and supramolecular assembly techniques. Template-assisted synthesis involves using pre-formed templates as scaffolds for the deposition of building blocks, which are subsequently removed to obtain the final nanocage structure. Sol-gel methods utilize the controlled hydrolysis and condensation of precursor molecules to form the cage

framework. Coordination chemistry exploits metal-ligand interactions to assemble the cage architecture, while supramolecular assembly relies on the self-organization of building blocks through non-covalent interactions. Drug Delivery: Nanocages hold great promise in targeted drug delivery systems. By encapsulating therapeutic molecules within their cavities, nanocages can protect them from degradation and deliver them to specific sites in the body. The selective binding of ligands on the cage surface enables targeted delivery to cells or tissues, reducing off-target effects and enhancing treatment efficacy.

Catalysis: Nanocages provide an ideal environment for catalytic reactions. The confined spaces within the cages can enhance reaction rates, improve selectivity, and stabilize reactive intermediates. Metal-based nanocages, in particular, exhibit remarkable catalytic properties, finding applications in diverse fields such as energy conversion, environmental remediation, and chemical synthesis. Sensing and Imaging: The unique optical, electronic, and magnetic properties of nanocages make them excellent candidates for sensing and imaging applications. By incorporating fluorescent or magnetic probes within their cavities, nanocages can serve as highly sensitive sensors for detecting analytes or as contrast agents for medical imaging techniques, including magnetic resonance imaging (MRI).

Energy Storage: Nanocages show promise in energy storage applications, such as batteries and supercapacitors. Their high surface area-to-volume ratio and well-defined cavities provide ample space for the storage and controlled release of ions or molecules.