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Emerging Trends In Bio-Synthesis and Applications of Gold Nanoparticles: A Blooming Technology

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ABSTRACT

Nanotechnology is a flourishing technology and a promising approach for treatment and diagnosis of a variety of diseases. Gold nanoparticles have recently emerged as an efficient tool for a variety of medical applications. Gold nanoparticles exploit their unique chemical and physical properties for transporting and unloading the pharmaceuticals. The gold core is essentially inert and non-toxic, mono-disperse nanoparticles can be formed with core sizes ranging from 1 nm to 150 nm, further adaptability is imparted by their ready functionalization; generally through thiol linkages. They are particularly promising for their easy synthesis in various shapes and the ability to target them to interact with specific molecules. Gold nanoparticles are being manufactured from gold chloride solutions using reductive reagents, to form colloidal suspensions.The common methods for synthesis of gold nanoparticles have been enlisted. The current review elaborates on the emerging and eco-friendly biosynthetic methods to synthesize gold nanoparticles. The biosynthetic processes involve predominantly green synthesis by using plants and their extracts and also fungus and bacteria. The biosynthetic process proves to be a boon over the chemical and other synthetic procedures by being economic, non-toxic and compatible. Gold nanoparticles have found their application in countless fields involving medicine and biology, cancer therapy, gene delivery, environmental sciences and in analytical technology. The present review explains the versatile gold nanoparticles and their innumerable applications.

Keywords: Gold nanoparticles, biosynthesis, plant extracts, bacteria, fungi, cancer therapy.

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INTRODUCTION

Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. Nanoparticles are sized between 1 and 100 nano-meters. A bulk material should have constant physical properties regardless of its size, but at the nano-scale size-dependent properties are often observed. Thus, the properties of materials change as their size approaches the nano-scale and as the percentage of atoms at the surface of a material becomes significant[1]

Nanotechnology has recently emerged as a promising approach for treatment and diagnosis of a variety of diseases. Gold nanoparticles (GNPs) are particularly promising for their easy synthesis in various shapes and the ability to conjugate them with peptides and proteins to target them to interact with specific molecules. In addition, GNPs experience plasmon resonance with light. This is a process whereby the electrons of the gold resonate in response to incoming radiation causing them to both absorb and scatter light. This effect can be harnessed to either destroy tissue by local heating or to release molecules of therapeutic importance.[16]

The interesting and sometimes unexpected properties of nanoparticles are therefore largely due to the large surface area of the material, which dominates the contributions made by the small bulk of the material.**Error! Bookmark not defined.**

SYNTHESIS OF NANOPARTICLES

The general chemistry followed for synthesizing gold nanoparticles in liquid (also known as "liquid chemical methods") is by reduction of chloroauric acid ($H[AuCl_4]$). The solution is rapidly stirred after dissolving $H[AuCl_4]$, and a reducing agent is added. This leads to Au^{3+}ions to be reduced to neutral gold atoms. The solution soon becomes supersaturated as more and more gold atoms are formed, and gold gradually starts to precipitate in the form of sub-nanometer particle size range. If the solution is stirred vigorously enough, particles of fairly uniform size are obtained. To prevent particle aggregation, some stabilizing agents that cover the nanoparticle surface are added[1].

The methods generally employed to synthesize gold nanoparticles are as follows:

TurkevichmethodError! Bookmark not defined.

This method was pioneered by J. Turkevich et al. in 1951and further developed by G. Frens in 1970s and is the simplest and widely used method for synthesizing gold nanoparticles. This method is used to produce mono-disperse spherical gold nanoparticles suspended in water of around 10–20 nm in diameter. The method involves reaction of small amounts of hot chloroauric acid with small amounts of sodium citrate solution. Here the citrate ions act as both a reducing agent, and a capping agent. However, larger particles can also be formed by adding lesser amount of sodium citrate (up to or less than to 0.05%) so that all the gold would not be reduced. As a result reduction in the amount of sodium citrate will reduce the amount of the citrate ions available for stabilizing the particles, and this will cause the small particles to aggregate into bigger ones until the total surface area of all particles becomes equivalent to that required to be covered by the existing citrate ions.

Brust method

The Brust methodwas discovered by Brust and Schiffrin in early 1990s and can be used to produce gold nanoparticles in organic liquids that are not miscible with water (e.g. toluene). It involves the reaction of a chlorauric acid solution with tetraoctylammonium bromide (TOAB) solution in toluene and sodium borohydride as an anti-coagulant and a reducing agent, respectively. The gold nanoparticles obtained by this method are around 5–6 nm in size. The solution aggregates gradually over the course of approximately two weeks as TOAB does not bind to the gold nanoparticles particularly strongly to the nanoparticles. This can be prevented by adding a stronger binding agent like thiol (e.g. alkanethiols) which has the capacity to produce near-permanent solutions as they bind to gold strongly. In order to remove the phase transfer agents bound to the nanoparticles and further purify them, soxhlet extraction can be performed[2].

Perrault Method

This method was discovered by Perrault and Chan in 2009 and makes use of hydroquinone to reduce $HAuCl_4$ in an aqueous solution that contains gold nanoparticle seeds. Similarly, gold nanoparticles can act in conjunction with hydroquinone to catalyze reduction of ionic gold onto their surface. Some stabilizer such as citrate can also be added for controlled particle growth. The hydroquinone method complements that of Frens, as it extends the range of mono-dispersed spherical particle sizes that can be produced. Whereas the Frens method is ideal for particles of 12-20 nm, the hydroquinone method can produce particles of at least 30–250 nm[3].

Sonolysis

This process is based on ultrasound which involves the reaction of an aqueous solution of $HAuCl_4$ with glucose. The reducing agents are hydroxyl radicals and sugar pyrolysis radicals (forming at the interfacial region between the collapsing cavities and the bulk water) and the morphology obtained is that of nano-ribbons with width 30–50 nm and length of several micrometers. When glucose is replaced by cyclodextrinonly spherical gold particles are obtained suggesting that glucose is essential in directing the morphology towards a ribbon.[4]

ADVANCED BIO-SYNTHETIC METHODS FOR GOLD NANOPARTICLES

Developing awareness towards green chemistry and other biological processes has led to the development of simple and eco-friendly approaches even towards the synthesis of nano-materials. Nanoparticles synthesized using biological processes are eco-friendly, non-toxic, economic and biocompatible. Biosynthesis of nano-materials has received a significant attention in the recent times owing to the use of mild experimental conditions such as temperature, pH, and pressure. If harnessed to their full potential, biological synthesis could offer an extra advantage over the chemical methods by way of higher productivity and lower cost[5].

Biological synthesis of metal nanoparticles by bacteria, fungi, actinomycetes, yeasts and plants have been reported. There are several organisms capable of synthesizing nanoparticles such as diatoms that produce siliceous materials or magnetostatic bacteria that synthesize magnetite nanoparticles. Biosynthesis of gold nanoparticles has been reported using bacteria, yeasts, actinomycetes, fungi and plants, such as the bacteria Brevibacterium casei, the fungus Aspergillusoryzae var. viridisor the plants tansy fruitand Syzygiumaromaticum. However, phytosynthesis of nano-materials is more advantageous than microbial synthesis due to tedious and time consuming processes related to growth and maintenance of microbial cultures.[10]

Phyto-synthesis of gold nanoparticles can be achieved by intra-cellular or extra-cellular reduction.Eukaryotes contain many proteins able to act as reducing agents and have the advantage of easy handling. Inrecent years, few plants such as Medicagosativaand Sesbaniadrummondiihave been reported to accumulate gold nanoparticles intracellularly. Extracts of Coriandrumsativum, Cymbopogonflexuosus, Emblicaofficianalis, Magnolia kobus, Psidiumguajavaand Tamarindusindicahave been successfully used to synthesize gold nanoparticles extracellularly. Production of both gold and silver has been reported by using the extracts of Aloe vera, Azadirachtaindica, Camellia sinensis, Cinnamomumcamphora, Diopyros kaki, PelargoniumgraveolensHibiscus rosasinesis, and Phyllanthusamarus. Gold nanoparticles of different shapes serving a variety of functions can be synthesized using different reducing agents. Considering the diversity of plants, the potential of plants for the synthesis of nanoparticles is yet to be fully explored[5].

Biosynthesis of gold nanoparticles using plants and plant extracts

Using plants for nanoparticle synthesis can be advantageous over other biological processes because it eliminates the elaborate process of maintaining cell cultures and can also be suitably scaled up for large-scale nanoparticle synthesis.[6]Laura Castro and co-workers reported biosynthesis of gold nanoparticles using aqueous chloroaurate ions and sugar beet pulp obtained as an industrial waste from the sugar industry. This was used as reducing agent. Sugar beet (Beta vulgaris) pulp is a residue obtained by heating sugar beet cossettes in water during the extraction of the juice used for the crystallization of sugar. The shape of the nanoparticles produced was controlled by varying the initial pH of the reaction medium. Triangular nanoplatesare produced at low pH and nanowires at high pH values.[1] Extracellular nanoparticle synthesis using plant leaf extracts rather than whole plants are more economical owing to easier downstream processing.Sastry and othersreported that nanoparticles can be synthesized using plant extractsat rates are comparable to those of chemical methods.

There have been recent reports on phytosynthesis of gold nanoparticles by employing coriander leaves, sundried Cinnamomumcamphoraleaves, phyllanthin extract, and purified apiin compound extracted from henna leaves. Shankar et al.reported pure metallic silver and gold nanoparticle synthesis by the reduction of Ag+ and Au3+ ions usingNeem (Azadirachtaindica) leaf broth. The time required for >90% reduction of Ag+ and Au3+ ions using Neem leaf broth was approximately 4 and 2 h, respectively. In case of neem leaf broth, terpenoids are believed to be the surface-active molecules stabilizing the nanoparticles, and the reaction of the metal ions is possibly facilitated by the reducing sugars and/or terpenoids present in the Neem leaf broth. Jae Yong Song et.al reported bio-synthesis of nanoparticles using leaf extracts of two plants, Magnolia kobus and Diopyros kaki. The particle size ranging from 5 to 300 nm and the shape of the plate and spherical structures could be controlled by changing the reaction temperature and leaf broth concentration.[22]

Green synthesis of gold nanoparticles has gained a wide attention in past decade. Green synthesis has not proved itself to be eco-friendly but also to be economical and scalable. Pei PeiGan and coworkers adopted one such eco-friendly method of green synthesis for synthesizing gold nanoparticles. They used palm oil mill effluent (POME) without adding external surfactant, capping agent or template. The representative TEM micrograph by counting 258 particles provided that predominantly spherical particles with an average size of 18.75 ± 5.96 nm were obtained. In addition, some triangular and hexagonal nanoparticles were also observed. The influence of various reaction parameters such as reaction pH, concentration of gold precursor and interaction time to the morphology and size of biosynthesized gold nanoparticles was investigated. This study shows the feasibility of using agro waste material for the biosynthesis of such metallic nanoparticles which is potentially more scalable, safe and economic due to its lower cost. It was observed that biomolecules secreted by the biomass can act as both reducing and capping agents during the reaction and can provide nanoparticles that are more biocompatible and safe. Biosynthesis of nanoparticles using POME was confirmed to be a simple, cost-effective and non-toxic method. The morphology and size of obtained gold nanoparticles could be controlled by varying the reaction conditions such as initial pH of the HAuCl4 solution and reaction temperature. Bioactive compounds involved in the biosynthesis are most likely proteins and water soluble polyphenols in POME that contains amine and carbonyl groups.[8]

Another approach was developed using Zingibe rofficinal extract which acts both as reducing and stabilizing agent. Z. Officinal extract is reported to be a more potent anti-platelet agent than aspirin. Therefore, green synthesis of gold nanoparticles with Z. officinaleextract, as an alternative to chemical synthesis, is beneficial from its biological and medical applications point of view, because of its good blood biocompatibility and physiological stability. It was observed that nanoparticles synthesised with Z. Officinal extract was highly stable at physiological condition as compared to citrate capped nanoparticles, which aggregated. Z. officinale (ginger) belonging to the family Zingibeaceae is considered as a more potent anti-platelet agent than aspirin with anti-inflammatory and analgesic properties similar to non-steroidal anti-inflammatory drugs, without the side effects of gastrointestinal bleeding and ulcer formation. Hence, stable gold nanoparticles synthesized with Z. officinale extract are highly beneficial for drug delivery, gene delivery and biosensor applications where there is a direct contact of these nanoparticles with blood.[9]

Biosynthesis of gold nanoparticles using bacteria and fungi

The available physical methods for the metal nanoparticle synthesis such as gas condensation and irradiation with ultraviolet radiation usually resulted in low production rate and high expenditure. Further, the large scale synthesis of metal nano materials suffers from certain drawbacks such as poly-dispersity and stability, especially if the reduction is carried outin aqueous media. Therefore, extracellular biological synthesis of metal nanoparticles provides a promising eco-friendly alternative for realizing large quantities of nanomaterials.[1]Beveridge and Murray found that gold nanoparticles could be precipitated within bacterial cells. Deplanche and Macaskie reported the bio recovery of gold by Escherichia coli and Desulfovibriode sulfuricans. In recent years, Pseudomonas aeruginosa has been used for the extracellular biosynthesis of gold nanoparticles with different sizes and shapes. The shape and size of gold nanoparticles produced by organisms can be controlled through changing experimental parameters related with growth mechanism. Metal bio-sorption takes place during gold nanoparticles synthesis. Bio-sorption is a promising process to recover precious metals from wastewaters using biomass of different kind.

Certain biomasses are able to bind and concentrate gold and other metals from even very dilute aqueous solutions.[9]

Regarding the mechanism of biological nanoparticle synthesis, it has been reported that reduction occurs due to the NADH dependent reductase released into the solution in case of gold nanoparticles synthesized extracellular by the fungus Fusariumoxysporum. It has also been suggested that nitroreductase enzymes may be involved in silver nanoparticle synthesis using the culture supernatants of Enterobacteria.[2] A. Mohammed Fayaz et.al experimented biosynthesis of extracellular gold nanoparticles by a thermophilic organism Geobacillusstearothermophiluson a laboratory scale. It was seen that thermophilic bacterium, G. Stearo thermo philus could be used for extracellular synthesis of gold nanoparticles. It was concluded that the nanoparticle solution acquired stability due to the secretion of certain reducing enzymes and capping proteins by the bacterium. The advantages offered by using a bacterium mediated synthesis of metallic nanoparticles include a toxin free synthesis along with economic viability of this method in terms of ease in handling the large scale synthesis.[1]In recent years certain enzymes are also used for synthesis of nanoparticles.Recently an eco-friendly method was developed to synthesize nanoparticles using purified enzyme laccase from fungal strains of Paraconiothyriumvariabile.[10]

Synthesis of gold nanoparticles using gram negative bacterium *pseudomonas fluorescens* extracellularly was also experimented. Pseudomonas species is ubiquitous Gamma subclass of Proteobacteria that are inhabitants of a wide range of soil, water and plant surfaces. P. fluorescenshas multiple flagella and an extremely versatile metabolism. It is an obligate aerobe. Nanoparticles synthesized using this approach ranged from 50-70 nm in size and was found to be stable.[11]Gold nanoparticles synthesized using Coleus amboinicus Lour as a reducing agent yielded spherical, truncated triangle, triangle, hexagonal and decahedral nanoparticles.[12]

In recent years it has been reported that amine-containing molecules such as chitosan, peptides and amino acids can reduce aqueous chloroaurate ions to gold nanoparticles.[6]

CHARACTERIZATION

After generation of the nanoparticles, the next important stage is the characterization. The characterization provides information about the size and shape of the nanoparticles and spectrum of the plasmon band. The most common characterization methods are electrical Impedance Spectroscopy (EIS), Surface Plasmon Resonance(SPR), cyclic voltammetry, Conductive measurement and high-resolution transmission electron microscopy (HRTEM).HRTEM gives a photograph of the gold core of the nanoparticles but the core dimensions can also be determined using scanning tunneling microscopy (STM), atomic force microscopy (AFM), small-angle X-ray scattering (SAXS), laser desorption ionization mass spectrometry (LDI-MS), and X-ray diffraction. Transmission electron microscopy (TEM) is also a powerful and straightforward method for the determination of size and shape of nanoparticles. In recent years, chemiresistive sensors based Gold Nanoparticles have also been developed for reliable detection.[13]

Structural and elemental characterizations of the gold nanorods can be carried out using X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-rays (EDX), atomic absorption spectrometry (AAS), and ultraviolet-visible spectrophotometry (UV-Vis).

M. Maciulevicius and co-workers designed and fabricated an online system for gold nanoparticle characterization. The mean diameter of nanoparticles was determined using their absorption spectra acquired in the real-time during the ablation experiments. . The technique was applied to investigate the effect of additional laser irradiation on size distribution in gold colloids prepared by laser ablation in water and in aqueous glucose solution. The laser ablation technique is one of the contaminant-free physical methods developed in recent years. The laser ablation in liquids provides much better opportunities to manipulate the size and other properties of nanoparticles. Specifically, ablation in liquids enables to control the size and size distribution of nanoparticles by the addition of various chemically active compounds into liquid solutions[14].

APPLICATIONS OF GOLD NANOPARTICLES

The array of applications for gold nanoparticles has grown rapidly and includes the following

Gold nanoparticles in medicine and biology [15]

Gold nanoparticles have come to the force as a promising new vehicle for drug and gene delivery. The poor stability of conventional drugs and genes in biological fluids, their enzymatic degradation, and difficulties in securing their penetration through some barrier or nucleus of cells are some of the unfavourable attributes of the existing technologies. The loading of gold nanoparticles with drugs or genes offers the prospect of greater control and increased therapeutic efficacy.[16]

The unique size and non-toxic nature of the nanoparticles makes it a suitable tool to be used in medicine and biology. Nanoparticles in range of 1 to 500 nm are extremely smaller than human cells which are about 10-20 μm. The unique optical, chemical, and biological properties of gold nanoparticles have resulted in becoming clinically important in several applications including drug and gene delivery. The attractive features of gold nanoparticles include their surface plasmon resonance, the controlled manner in which they interact with thiol groups, and their non-toxic nature. These attributes can be exploited to provide an effective and selective platform to obtain a targeted intracellular release of some substance. Nanoparticles have sizes similar to that of the biomolecules present at the cellular level. This specific size of nanoparticles promotes development of nano-devices and nano-sensors that can go deep inside the cells to probe proteins or the DNA both inside and outside the cell. This interest has been stimulated by the capability of the gold nanoparticles to bind a wide range of organic molecules, their low level of toxicity, and their strong and tunable optical absorption. This has resulted in a broad array of studies in which gold nanoparticles have played a role as drug and vaccine carriers into target cells or specific tissues. Generally, this has been achieved by modifying the surface of the gold nanoparticles so that they can bind to the specific targeting drugs or other biomolecules. The delivery of drugs with nanoparticles can result in higher concentrations than possible with normal drug delivery schemes which, for example, could increase the overall efficiency of a drug used to destroy pathogenic cells. Furthermore, the unique chemical, physical, and photo-physical properties of gold nanoparticles can be exploited in innovative ways to control the transport and controlled release of pharmaceutical compounds.

Gold nanoparticles and bio-sensors [17]

Sensors are devices that produce measurable responses to changes in physical conditions or chemical concentrations. Biosensors defined as sensors that consist of biological recognition elements, often called bio-receptors, or transducers. Assens or comprises a sensing element and a signal transducer, and produces a signal proportional to the analyte concentration. With the recent advances in nanotechnology, nanomaterials have received great interests in the field of biosensors due to their exquisite sensitivity in chemical and biological sensing. The principle involved in the design of a biosensor based on gold nanoparticles is that the gold nanoparticles are functionalized with a thiolated biomolecule which upon identifying specific biomolecule brings about change in the optical absorption of gold nanoparticles.

Antimicrobials

It is very essential to eliminate bacteria present in water in order to avoid problems related to health. *Escherichia coli* and *Salmonella typhi* bacteria are two common pollutants and they develop resistance to some of the commonly used bactericide. The gold nanoparticles are anticipated to inhibit the growth of these two microorganisms.The gold-supported antimicrobial activity against *Escherichia coli* and *Salmonella typhihasproved to be beneficial*as the two bacteria currently present in foods and water have developed more and more resistance to silver-based antimicrobials. [18]

Cancer therapy [19,20]

Gold nanoparticles have a good property of scattering and absorbing light. The gold nanoparticle have a unique property of binding to the cancerous cells specifically due to the presence of Epidermal Growth Factor Receptor (EGFR) all over the surface of the cancerous cells. However, the healthy cells do not express such protein on their surface. Gold nanoparticles conjugate with this antibody (EFGR) specifically, called as anti-EFGR. Hence, when detected using suitable techniques it was found that cancer cells shine whereas healthy cells do not, which can aid in identification of the cancerous cells. It was also seen that gold nanoparticles have 600 times more affinity towards cancer cells than the non-cancerous cells.

The main problem with many currently available cancer treatments is that they cannot be precisely targeted. As it is very hard to get an effective drug, such as paclitaxel, directly to the tumour, large doses are needed in the hope that enough of the drug will reach the diseased cells where it is needed. Gold nanoparticles are being investigated as carriers for drugs such as Paclitaxel. Recently gold nanoparticles have found a role to deliver drug easily. Cancer therapy has various routes such as chemotherapy, photo-thermal therapy and radiotherapy. Gold nanoparticles have been investigated as potential candidates to aid in photo-thermal therapy and radiotherapy. It is important to understand the difference between normal and cancerous tissue to efficiently improve hybrid nanoparticles in cancer diagnosis and treatment. Above all use of gold nanoparticles in cancer treatment is nontoxic, inexpensive and a simple one.

Near-IR absorbing gold nanoparticles which include gold nanoshells and nanorods produce heat when excited by light at wavelengths from 700 to 800 nm. This enables these nanoparticles to eradicate targeted tumors. When light is applied to a tumor containing gold nanoparticles, the particles rapidly heat up, killing tumor cells in a treatment known as hyperthermia therapy also known as Photodynamic Therapy.

Diagnostics

Gold nanoparticles are also used to detect biomarkers in the diagnosis of heart diseases, cancers, and infectious agents. They are also commonly used in lateral flow immunoassays, a common household example being the home pregnancy test.[21]

Needle-free drug delivery

Gold-based technologies are also provide a unique needle-free delivery system, a technique that used gold nanoparticles and allowed vaccines to be delivered through the skin making use of the fact that small particles can pass through gaps between cells while large ones cannot. [12]**Error! Bookmark not defined.**

Gold nanoparticles against HIV/AIDS

One of the most efficient usages of gold nanoparticles in recent years is detecting and fighting against HIV. The release of a drug from gold nanoparticles could proceed via internal stimuli generally operated in a biologically controlled manner; such as pH or glutathione or via external stimuli operated with the support of stimuli-generating processes; such as the application of light.[22]

Gold nanoparticle conjugates in drug delivery systems

A strong motivation for the new field of 'nano-medicine' is that ithas the potential to dramatically improve therapeutic outcomes indrug-related therapies. Gold nanoparticles are one of the materialsthat are frequently mentioned in respect of nano-medical research andthe conjugation of gold nanoparticles to specific drugs is one of thepossibilities often cited. The motivation for this is the enhanced targeting and delivery of drug to target cells that might be obtained.

Generally, there are two types of targeting, designated as 'active' and 'passive'. The term 'passive targeting' most commonly refers to theaccumulation of nanoparticles or pharmaceutical substances at as pecific site by physiochemical factors (e.g. size, molecular weight),extra vasation, or pharmacological factors. In the case of 'active targeting', the nanoparticle or drug molecule has been conjugated with a specific active molecule that binds to the desired target cells or tissues. For example, gold nanoparticles can be targeted to specific phagocytic cells or to tumours. In the case of nanoparticles, modification and functionalization of the surface of the nanoparticle plays a major role in this kind of targeting.[20]

Gene delivery

As we have shown, drug delivery systems based on nanoparticles offer some opportunities to improve the solubility, optimal bio-distribution, in vivo stability, and pharmacokinetics of drugs. They can also be used to carry nucleic acids. Generally, the use of nucleic acids to treat and control diseases is termed 'gene therapy'. This type of therapy can be carried out by using viral and non-viral vectors to transport foreign genes into somatic cells to remedy defective genes there or provide additional biological functions. The use of viruses as avehicle for gene therapy is now well known, however, viral vectors have disadvantages such as irregular cytotoxicity, the stimulation of an immune response, limitations in targeting specific cell types, low DNA carrying capacity, lack of ability to infect non-dividing cells, and difficulties in production and packaging.

In contrast, non-viral gene delivery systems provide some potential benefits and have low toxicity. Unfortunately, the current non-viral gene delivery systems still suffer from low transfection efficiency due to the difficulty of controlling the process at the nano-scale. All the known vectors must overcome several barriers between the site of administration and the cell nucleus. These difficulties include surviving the extracellular environment and the route to the target cells, successfully crossing the cellular membrane, protection of the nucleic acid from nuclease degradation and, finally, release of the functional form of the nucleic acid in the nucleus.[23]

For environment

Gold nanoparticle-based technologies provide solution to some of environmentally great issues, such as greener production methods, pollution control and water purification. Gold is indeed one of the stable metals, and it is resistant to oxidation. This ability of gold nanoparticles provides conditions to make many catalyst containing: Catalysis of CO Oxidation, Catalysis of Hydrogenation of Unsaturated Substrates, Electrochemical Redox Catalysis of CO and CH_3OH Oxidation and O_2 Reduction, Catalysis by Functional Thiolate-Stabilized gold nanoparticles etc.[24]

Mercury control and sensing

Nanotechnology can control and sense mercury using gold nanoparticles. Mercury is one of very toxic material that exists all over the world. Mercury can cause some diseases such as Alzheimer and autism. Almost over 100 tonnes of mercury finds its way into the atmosphere every year, mercury exit from some boilers in the utilities industry. Gold-based catalysts can provide a solution to this problem. Gold nanoparticles have considerable promise as mercury oxidation catalysts. [23]

Improving water and air quality

One of the most useful applications of gold nanoparticles is increasing water and air quality, Carbon monoxide is a colourless, odourless gas which is very toxic to humans. Gold nanoparticles provide as impel solution. Gold nanoparticles allow the oxidation of CO to carbon dioxide (CO_2) that transforms an acutely dangerous gas to a far less toxic substance. Recent years have seen a sharp rise in the use of noble metal nanoparticlesfor water purification and contaminant detection.[23]

Gold nanoparticles in technology

In recent years gold nanoparticles have found novel abilities in various fields of science such as coating glasses to change their properties and multicolour optical coding for biological assays. Gold nanoparticles are being used to enhance electroluminescence and quantum efficiency in organic light emitting diodes. Application of nanoparticles for signal amplification is another novel and developed applications of these nanoparticles. Besides, gold nanoparticles are used in making advanced dyes and pigments. Gold nanoparticles have also occasionally been used to dye textiles.[25]

Probes

Gold nanoparticles scatter light and can produce an array of colours under dark-field microscopy. The scattered colours of gold nanoparticles are currently used for biological imaging applications. Also gold nanoparticles are relatively dense, making them useful as probes for transmission electron microscopy.[12]

CONCLUSION

Gold nanoparticles have found novel abilities in various fields of science especially medicine and technology and thus plays a vital role in the new age. Gold nanoparticles have received significant attention in recent years due to their unique electronic, photonic, and catalytic properties that have led to several technological and biomedical applications. Experiments have been conducted like synthesizing functionalized gold nanoparticles with carboxylic groups and have been used as crosslinking agents for the preparation of PVA hydrogels. It involves functionalization of gold nanoparticles with a vinyl group that allows the gold nanoparticles to be attached to the polymer chains by covalent bonds. In this way, gold nanoparticle/poly(N-isopropylacrylamide) composites have been obtained with excellent thermo-switchable electrical properties upon controlling the inter-particle distance under temperature stimuli. Gold nanoparticles are versatile materials for a broad range of applications with well characterized electronic and physical properties and well-developed synthesis procedures. The newly emerged bio-synthetic procedures have enlightened this technology to a different level by making it eco-friendly, cost effective, non-toxic, compatible and versatile. Especially, green chemistry approach is amenable to large-scale commercial production. Furthermore, their surface chemistry is also easy to modify. These features have made gold nanoparticles one of the most widely used nanomaterials for research and an integral component of medical devices and industrial products all over the world. Thus, this technology being a blooming science is reliable with many innovative applications and is endowed with a bright future in the imminent years.

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