**Nanoparticle– A Compendium on Biosynthesis, Application and Toxicological Effects**

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**Abstract:**

In recent decades, there has been a surge of interest in nanomaterials, particularly nanoparticles, due to their unique physical and chemical properties that differ from bulk materials. These exceptional properties have opened up numerous innovative applications in medicine, electronics, agriculture, chemical catalysis, the food industry, and other fields. Recently, nanoparticles are also being produced biologically through plant or microorganism-mediated processes, which is a more environmentally friendly alternative to traditional physical and chemical synthesis methods. This multidisciplinary approach requires biologists and biotechnologists to understand and learn how to characterize these processes. This review article focuses on providing a comprehensive overview of the classification of nanoparticles, characterization, biosynthesis and application. The article presents comprehensive methods and techniques used for the biosynthesis and analysis of these properties, along with a large collection of examples of nanocomposite nanoparticles, and their application. The aim of this review is to make the various methods more accessible to readers and to assist them in identifying the appropriate methodology for any given nanoscience problem.

**Keywords:** Nanomaterial, Biosynthesis, Nanocomposite, Nanosciences, Toxicological effect.

**Introduction:**

A nanoparticle or ultrafine particle is usually defined as a particle of [matter](https://en.wikipedia.org/wiki/Matter) that is between 1 and 100 [nanometres](https://en.wikipedia.org/wiki/Nanometre) (nm) in [diameter](https://en.wikipedia.org/wiki/Diameter). The term is sometimes used for larger particles, up to 500 nm, or fibers and tubes that are less than 100 nm in only two directions. At the lowest range, metal particles smaller than 1 nm are usually called [atom clusters](https://en.wikipedia.org/wiki/Atom_cluster) instead.

Nanoparticles are usually distinguished from [microparticles](https://en.wikipedia.org/wiki/Microparticle%22%20%5Co%20%22Microparticle) (1-1000 µm), "fine particles" (sized between 100 and 2500 nm), and "coarse particles" (ranging from 2500 to 10,000 nm), because their smaller size drives very different physical or chemical properties, like colloidal properties and ultrafast optical effectsor electric properties.

**Classification:**

Based on their composition, NPs are generally placed into three classes: organic, carbon-based, and inorganic.

**Organic NPs**

This class comprises NPs that are made of proteins, carbohydrates, lipids, polymers, or any other organic compounds. The most prominent examples of this class are dendrimers, liposomes, micelles, and protein complexes such as ferritin (shown in Fig.  below). These NPs aretypically non-toxic, bio-degradable, and can in some cases, e.g., for liposomes, have a hollow core. Organic NPs are sensitive to thermal and electromagnetic radiation such as heat and light. In addition, they are often formed by non-covalent intermolecular interactions, which makes them more labile in nature and offers a route for clearance from the body. There are different parameters that determine the potential field of application of organic NPs, e.g., composition, surface morphology, stability, carrying capacity, etc*.* Today, organic NPs are mostly used in the biomedical field in targeted drug delivery and cancer therapy.



# Types of organic NPs. A Dendrimers; B liposomes; C micelles; and D ferritin

**Carbon-based NPs**

This class comprises NPs that are made solely from carbon atoms. Famous examples of this class are fullerenes, carbon black NPs, and carbon quantum dots (shown in Fig. below). Fullerenes are carbon molecules that are characterized by a symmetrical closed-cage structure. C60 fullerenes consist of 60 carbon atoms arranged in the shape of a soccer ball, but also other types of fullerenes such as C70 and C540 fullerenes have been described. Carbon black NPs are grape-like aggregates of highly fused spherical particles. Carbon quantum dots consist of discrete, quasi-spherical carbon NPs with sizes below 10 nm. Carbon-based NPs unite the distinctive properties of sp2-hybridized carbon bonds with the unusual physicochemical properties at the nanoscale. Due to their unique electrical conductivity, high strength, electron affinity, optical, thermal, and sorption properties, carbon-based NPs are used in a wide range of application such as drug delivery, energy storage, bioimaging, photovoltaic devices, and environmental sensing applications to monitor microbial ecology or to detect microbial pathogens. Nanodiamonds and carbon nano onions are more complex, carbon-based NPs. Due to their characteristic low toxicity and biocompatibility, they are used in drug delivery and tissue engineering applications.



# Different types of carbon-based NPs. A C60 fullerene; B carbon black NPs; and C carbon quantum dots

**Inorganic NPs**

This class comprises NPs that not made of carbon or organic materials. The typical examples of this class are metal, ceramic, and semiconductor NPs. Metal NPs are purely made of metal precursors, they can be monometallic, bimetallic, or polymetallic. Bimetallic NPs can be made from alloys or formed in different layers (core–shell). Due to the localized surface plasmon resonance characteristics, these NPs possess unique optical and electricals properties. In addition, some metal NPs also possess unique thermal, magnetic, and biological properties. This makes them increasingly important materials for the development of nanodevices that can be used in numerous physical, chemical, biological, biomedical, and pharmaceutical applications (these applications are discussed in detail later in the applications section of the review). In present days, the size-, shape-, and facet-controlled synthesis of metal NPs is important for creating cutting-edge materials.

Semiconductor NPs are made of semiconductor materials, which possess properties between metals and non-metals. These NPs possess unique wide bandgaps and show significant alteration in their properties with bandgap tuning compared to bulk semiconductor materials. As a result, these NPs are important materials in photocatalysis, optic, and electronic devices. Ceramic NPs are inorganic solids made of carbonates, carbides, phosphates, and oxides of metals and metalloids, such as titanium and calcium. They are usually synthesized via heat and successive cooling and they can be found in amorphous, polycrystalline, dense, porous or hollow forms. They are mainly used in biomedical applications due to their high stability and high load capacity. Nevertheless, they are also used in other applications such as catalysis, degradation of dyes, photonics and optoelectronics.

For most nanocomposite materials, the process of incorporating nanoparticles is not straightforward. Nanoparticles are notoriously prone to agglomeration, resulting in the formation of large clumps that are difficult to redisperse. In addition, nanoparticles do not always retain their unique size-related properties when they are incorporated into a composite material.

**Biosynthesis:**

Biosynthesis of nanoparticles by microorganisms is a green and eco-friendly technology. Diverse microorganisms, bothprokaryotes and eukaryotes are used for synthesis of metallic nanoparticles viz. silver, gold, platinum, zirconium, palladium, iron, cadmium and metal oxides such as titanium oxide, zinc oxide, etc. These microorganisms include bacteria, actinomycetes, fungi and algae. The synthesis of nanoparticles may be intracellular or extracellular according to the location of nanoparticles.

**Physical Vapour Deposition**:

This method usually involves use of materials of interest as sources of evaporation. An inert gas or reactive gas for collisions with material vapour. A cold finger on which nanoparticles can condense, a scraper to scrape nanoparticles and piston-anvil. All the processes are carried out in a vaccum chamber so that the desired purity of the end product can be obtained. Generally, high vapour pressure metal oxides are evaporated from filaments of refractory metals like W, Ta, Mo in which the materials to be evaporated are held. The density of the evaporated material close to the source is quite high and particle size is small (5nm) such particles would prefer to acquire a stable lower energy state. Due to small particle –particle interaction bigger particles can be formed. Hence, they should be removed away from the source as fast as possible. This is done by forcing an inert gas near the source, which removes the particles from the vicinity of the source. In general, the rate of evaporation and the pressure of gases inside the chamber determine the particle size. Evaporated atoms and clusters tend to colloid with gas molecules and make bigger particles, which condense on cold finger. While moving away from cold finger the clusters grow. If clusters have been formed on inert gas molecules or atoms, on reaching the cold finger, gas atoms may leave the particles there and then escape to the gas phase. If the reactive gases like O2, N2, H2 and NH3 etc. are used in the system, evaporated material can interact with these gases forming oxide, nitride, or hydride particles. Size, shape of the evaporated material can depend upon the gas pressure in deposition chamber. Using gas pressure of H2 more than 500 K Pa. TiH2 particles of ~ 12nm size can be produced.

**B. Laser Ablation:**

In this method, vapourization of the material is effected using pulses of laser beam of high power. The setup is high vaccum system equipped with inert gas introduction facility, laser beam. Clusters of any material of which solid target can be made are possible to synthesize. Laser which gives UV wavelength such as excimer laser is required as other wavelengths like IR or visible are often are reflected by some of the metal surfaces. A powerful beam of laser evaporates the atoms from a solid source and atoms colloide with inert gas atoms and cool on them forming clusters. They condense on the cooled substrate. This method is known as laser ablation. Single wall Carbon Nanotubes (SWNT) is mostly synthesized by this method.

**Chemical Methods**

**A. Colloids synthesis:**

These are the phase separated sub micrometer particles in the form of spherical particles, rods, tubes and plates etc. These are the particles suspended in some hot matrix. Metal, alloy, semiconductor and insulator particles of different sizes and shapes can be synthesized in aqueous or non-aqueous medium. Synthesis of colloids is a very old method. M. Faraday synthesized gold nanoparticles by wet chemical route. The particles are so stable. Colloidal particles are synthesized in a glass reactor. Glass reactor has a provision to introduce some precursors, gases as well as measure temperature, pH etc; during the reaction. It is possible to remove the products at suitable time intervals. Reaction is carried out under inert atmosphere so as to avoid any uncontrolled oxidation of the products.

**B. Synthesis of Metal Nanoparticles by Colloidal**

This process is done by reduction of some metal salt or acid.For example copper particles can be obtained by reducingChloroauric acid (HAuCl4) with tri sodium citrate(Na3C6H5O7). The reaction will be,HAuCl4 + Na3C6H5O7 Au+ + C6H5O7 + HCl +3 NaClThe reaction will be carried out in water. Obtainednanoparticles exhibit colour depending upon the particle size. i.e. (intense red colour for gold metal). In similar way Silver, Gold, Palladium and few other metal nanoparticlescan be synthesized using appropriate precursors,temperature, pH, duration of synthesis etc.

**C. Sol-Gel Method:**

In this method two types of materials or compounds ‘sol ‘and ‘gel’ involves. This process is a low temperature process, hence less energy consumption and less pollution. Sols are solid particles in a liquid. They are a sub class of colloids. Gels are nothing but a continuous network of particles with pores filled with liquid. A sol gel process involves formation of sols in a liquid and then connecting the sol particles to form a network. By drying the liquid, it is possible to obtain powders and thin films. This method is useful to synthesize ceramics or metal oxides, sulphides, borides and nitrides. Sol-gel synthesis involves hydrolysis of precursors, condensation followed by polycondensation to form particles, gelation and drying process by various routes. Precursors are to be chosen so that they have a tendency to form gels. Both alkoxides and metal salts can be used. It is also possible to synthesize nanoparticles like nanorods, nanotubes etc. by sol-gel technique.

**Biological Methods**

**A. Synthesis using Plant Extracts:**

Use of plants in synthesis of nanoparticles is quite less studied area as compared to use of micro-organisms to produce nanoparticles. There are few examples which suggest that plant extracts can be used in synthesis of nanoparticles. To obtain gold nanoparticles from geranium plant extract is discussed here. Finely crushed leaves are put in Erlenmeyer flask and boiled in water just for a minute. Leaves get ruptured and cells release intracellular material.

Solution is cooled and decanted. This solution is added to HAuCl4 aqueous solution, and nanoparticles of gold starts forming with a minutes.

**B. Synthesis using DNA:**

CdS nanoparticles can be synthesized by DNA. DNA is used to bind the surface of growing nanoparticles. For example, double standard Salmon Sprem DNA can be sheared to an average size of 500bp. Cadmium acetate can be added to desired medium like water, ethanol, propanol, etc. and reaction is carried out in a glass flask with facility to purge the solution and flow with an inert gas like nitrogen. Addition of DNA should be made and then Na2S can be added drop wise. Depending upon the concentrations of cadmium acetate, sodium chloride DNA nanoparticles of CdS with sizes less than ~ 10 nm can be obtained. It is found that CdS nanoparticles synthesized by this method have cadmium rich surface. DNA probably bends through its negatively charged phosphate group to positively charged (Cd+) nanoparticles surface. The other end of DNA is in fact free to interact with suitable proteins. Nanoparticles prepared by this way are used as sensors of proteins.

**Intracellular synthesis of nanoparticles by fungi:**

This method involves transport of ions into microbial cells to form nanoparticles in the presence of enzymes. As compared to the size of extracellularly reduced nanoparticles, the nanoparticles formed inside the organism are smaller. The size limit is probably related to the particles nucleating inside the organisms"

**Extracellular synthesis of nanoparticles by fungi:**

Extracellular synthesis of nanoparticles has more applications as compared to intracellular synthesis since it is void of unnecessary adjoining cellular components from the cell. Mostly, fungi are known to produce nanoparticles extracellularly because of their enormous secretory components, which are involved in the reduction and capping of nanoparticles.

**Microbes for production of nanoparticles:**

Both unicellular and multicellular organisms produce inorganic materials either intra- or extracellularly. The ability of microorganisms like bacteria and fungi to control the synthesis of metallic nanoparticles is employed in the search for new materials.

**Aplication**

**Nanoparticle applications as nanocomposites:**

Despite the difficulties with manufacture, the use of nanomaterials grew markedly in the early 21st century, with especially rapid growth in the use of nanocomposites. Nanocomposites were employed in the development and design of new materials, serving, for example, as the building blocks for new [dielectric](https://www.britannica.com/science/dielectric) (insulating) and magnetic materials. The following sections describe some of the many applications of nanoparticles and nanocomposites in materials.

**Polymers**

Similar to the way in which carbon and silica nanoparticles have been used as fillers in rubber to improve the mechanical properties of tires, such particles and others, including nanoclays, have been incorporated into [polymers](https://www.britannica.com/science/polymer) to improve their strength and impact resistance. In the early 21st century, increasing use of non-[petroleum](https://www.britannica.com/science/petroleum)-based polymers that were [derived](https://www.britannica.com/dictionary/derived) from natural sources drove the development of “all-natural” nanocomposite polymers. Such materials incorporate a biopolymer derived from an alginate (a carbohydrate found in the [cell wall](https://www.britannica.com/science/cell-wall-plant-anatomy) of [brown algae](https://www.britannica.com/science/brown-algae)), [cellulose](https://www.britannica.com/science/cellulose), or [starch](https://www.britannica.com/science/starch); the biopolymer is used in conjunction with a natural nanoclay or a filler derived from the shells of [crustaceans](https://www.britannica.com/animal/crustacean). The materials are biodegradable and do not leave behind potentially harmful or nonnatural residues.

**Food packaging**

Nanoparticles have been increasingly incorporated into food packaging to control the ambient atmosphere around food, keeping it fresh and safe from microbial contamination. Such composites use nanoflakes of [clays](https://www.britannica.com/science/clay-mineral) and claylike particles, which slow down the [ingress](https://www.britannica.com/dictionary/ingress) of moisture and reduce gas transport across the packaging film. It is also possible to incorporate nanoparticles with apparent antimicrobial effects (e.g., nanocopper or nanosilver) into such packaging. Nanoparticles that exhibit antimicrobial activity had also been incorporated into [paints](https://www.britannica.com/technology/paint) and coatings, making those products particularly useful for surfaces in [hospitals](https://www.britannica.com/science/hospital) and other medical facilities and in areas of food preparation.

**Flame retardants**

Nanoparticles were explored for their potential to replace additives based on flammable organic [halogens](https://www.britannica.com/science/halogen) and phosphorus in [plastics](https://www.britannica.com/science/plastic) and [textiles](https://www.britannica.com/topic/textile). Studies had suggested that, in the event of a serious [fire](https://www.britannica.com/science/fire-combustion), products with nanoclays and hydroxide nanoparticles were associated with fewer emissions of harmful fumes than products containing certain other types of additives.

**Batteries and supercapacitors**

The ability to engineer nanocomposite materials to have very high internal surface areas for storing [electrical charge](https://www.britannica.com/science/electric-charge) in the form of small [ions](https://www.britannica.com/science/ion-physics) or [electrons](https://www.britannica.com/science/electron) has made them especially valuable for use in [batteries](https://www.britannica.com/technology/battery-electronics) and supercapacitors. Indeed, nanocomposite materials have been synthesized for various applications involving [electrodes](https://www.britannica.com/science/electrode). Composite materials based on carbon nanotubes and layered-type materials, such as [graphene](https://www.britannica.com/science/graphene), were also researched extensively, making their first appearances in commercial devices in the early 2000s.

**Nanoceramics**

A long-term objective in [materials science](https://www.britannica.com/technology/materials-science) had been to transform [ceramics](https://www.britannica.com/technology/ceramic-composition-and-properties) that are brittle and prone to cracking into tougher, more [resilient](https://www.merriam-webster.com/dictionary/resilient) materials. By the early 21st century, researchers had achieved that goal by incorporating an effective blend of nanoparticles into ceramics materials. Other new ceramics materials that were under development included all-ceramic or polymer-ceramic blends, which combined the unique functional (e.g., electrical, magnetic, or mechanical) properties of a nanocomposite material with the properties of ceramics materials.

**Light control**

In the 1990s the development of blue light-emitting diodes ([LEDs](https://www.britannica.com/technology/LED)), which had the potential to produce white [light](https://www.britannica.com/science/light) at significantly reduced costs, inspired a revolution in [lighting](https://www.britannica.com/technology/lighting). Blue LEDs brought about a need for composite materials that could be used to coat the [diodes](https://www.britannica.com/technology/diode) to convert blue light into other [wavelengths](https://www.britannica.com/science/wavelength) (such as red, yellow, or green) in order to achieve white light. One way of obtaining the desired light is by leveraging the size or [quantum](https://www.britannica.com/science/quantum) effect of small semiconducting particles. The application of such particles [facilitated](https://www.merriam-webster.com/dictionary/facilitated) the development of nanocomposite polymers for [greenhouse](https://www.britannica.com/topic/greenhouse) enclosures; the polymers optimize [plant](https://www.britannica.com/plant/plant) growth by effectively converting wavelengths of full-spectrum [sunlight](https://www.britannica.com/science/sunlight-solar-radiation) into the red and blue wavelengths used in [photosynthesis](https://www.britannica.com/science/photosynthesis). Light conversion in the above cases is achieved with submicron particles of inorganic phosphor materials incorporated into the [polymer](https://www.britannica.com/science/polymer).

**Nanoparticle applications in medicine**

The small size of nanoparticles is especially advantageous in medicine; nanoparticles can not only circulate widely throughout the body but also enter [cells](https://www.britannica.com/science/cell-biology) or be designed to bind to specific cells. Those properties have enabled new ways of [enhancing](https://www.merriam-webster.com/dictionary/enhancing) images of [organs](https://www.britannica.com/science/organ-biology) as well as [tumours](https://www.britannica.com/science/tumor) and other diseased [tissues](https://www.britannica.com/science/tissue) in the body. They also have [facilitated](https://www.merriam-webster.com/dictionary/facilitated) the development of new methods of delivering therapy, such as by providing local heating (hyperthermia), by blocking vasculature to diseased tissues and tumours, or by carrying payloads of [drugs](https://www.britannica.com/science/drug-chemical-agent).

Magnetic nanoparticles have been used to replace radioactive [technetium](https://www.britannica.com/science/technetium) for tracking the spread of [cancer](https://www.britannica.com/science/cancer-disease) along [lymph nodes](https://www.britannica.com/science/lymph-node). The nanoparticles work by exploiting the change in contrast brought about by tiny particles of superparamagnetic iron [oxide](https://www.britannica.com/science/oxide) in [magnetic resonance imaging](https://www.britannica.com/science/magnetic-resonance-imaging) (MRI). Such particles also can be used to kill tumours via hyperthermia, in which an alternating [magnetic field](https://www.britannica.com/science/magnetic-field) causes them to heat and destroy tissue on a local scale.

Nanoparticles can be designed to [enhance](https://www.merriam-webster.com/dictionary/enhance) fluorescent imaging or to enhance images from [positron emission tomography](https://www.britannica.com/topic/positron-emission-tomography) (PET) or [ultrasound](https://www.britannica.com/science/ultrasound). Those methods typically require that the nanoparticle be able to recognize a particular cell or disease state. In theory, the same idea of targeting could be used in aiding the precise delivery of a drug to a given disease site. The drug could be carried via a nanocapsule or a liposome, or it could be carried in a porous nanosponge structure and then held by bonds at the targeted site, thereby allowing the slow release of drug. The development of nanoparticles to aid in the delivery of a drug to the [brain](https://www.britannica.com/science/brain) via inhalation holds considerable promise for the [treatment](https://www.britannica.com/dictionary/treatment) of neurological disorders such as [Parkinson disease](https://www.britannica.com/science/Parkinson-disease), [Alzheimer disease](https://www.britannica.com/science/Alzheimer-disease), and [multiple sclerosis](https://www.britannica.com/science/multiple-sclerosis).

Nanoparticles and nanofibres play an important part in the design and manufacture of novel scaffold structures for tissue and [bone](https://www.britannica.com/science/bone-anatomy) repair. The nanomaterials used in such scaffolds are biocompatible. For example, nanoparticles of calcium hydroxyapatite, a natural component of bone, used in combination with [collagen](https://www.britannica.com/science/collagen) or collagen substitutes could be used in future tissue-repair therapies.

Nanoparticles also have been used in the development of health-related products. For example, a [sunscreen](https://www.britannica.com/science/sunscreen) known as Optisol, invented at the [University of Oxford](https://www.britannica.com/topic/University-of-Oxford) in the 1990s, was designed with the objective of developing a safe sunscreen that was transparent in visible light but retained [ultraviolet](https://www.britannica.com/science/ultraviolet-radiation)-blocking action on the [skin](https://www.britannica.com/science/human-skin). The ingredients traditionally used in sunscreens were based on large particles of either zinc oxide or [titanium dioxide](https://www.britannica.com/science/titanium-dioxide) or contained an organic sunlight-absorbing [compound](https://www.merriam-webster.com/dictionary/compound). However, those materials were not satisfactory: zinc oxide and titanium dioxide are very potent photocatalysts, and in the presence of water and sunlight they generate free radicals, which have the potential to damage skin cells and [DNA](https://www.britannica.com/science/DNA) (deoxyribonucleic acid). Scientists proceeded to develop a nanoparticle form of titanium oxide that contained a small amount of [manganese](https://www.britannica.com/science/manganese). Studies indicated that the nanoparticle-based sunscreen was safer than sunscreen products manufactured by using traditional materials. The improvement in safety was attributed to the introduction of manganese, which changed the semiconducting properties of the compound from n-type to p-type, thus shifting its [Fermi level](https://www.britannica.com/science/Fermi-level), or oxidation-reduction properties, and making the generation of free radicals less likely.

**Toxicological Effects of Nanoparticle:**

Apart from their widespread use in industry and medicine, NPs and other nanomaterials have been linked to certain toxicities, which are now receiving more attention than ever before. For instance, NPs may penetrate the dendritic cells of the airway wall, which are the primary antigen-presenting cells that play important roles in coordinating the innate and adaptive immune systems. While targeting dendritic cells with nanotechnology is a promising strategy for cancer immunotherapy, studies have shown that the absorption of NPs can impair the function of these cells. The physicochemical properties of NPs also affect their interactions with dendritic cells, thus altering their immune functions in various processes such as maturation, homing, antigen processing, and antigen presentation. There are concerns regarding whether standard toxicological methods can detect any dysfunction of these cells or whether any such effects are relatively minor. As nanotechnology continues to advance, there will likely be increasing exposure to a wider range of NPs, and this will undoubtedly lead to proposals for their use.

**Table. Nanoparticle-induced toxicities in different organs.**

|  |  |  |
| --- | --- | --- |
| Brain | MNPs@SiO2 (RITC) | Silica-coated magnetic NPs activate microglia and induce neurotoxic D-serine secretion |
| IONP  | The Neurotoxic potential of iron oxide NPs in Wistar Rats |
| Carbon black nanoparticles (CBNPs)  | Exposure of carbon black NPs to chicken embryos |
| ZrO2 NP  | Breakthrough of ZrO2 NPs into fetal brains depends on the developmental stage of the maternal placental barrier and fetal blood-brain barrier |
| Silicon dioxide NPs  | Silicon dioxide NPs induced neurobehavioral impairments by disrupting microbiota–gut–brain axis. |
| zinc oxide NPs  | Crosstalk of gut microbiota and serum/hippocampus metabolites in neurobehavioral impairments induced by zinc oxide NPs. |
| Silica NPs  | Silica NPs promote α-Synuclein aggregation and Parkinson’s disease pathology. |
| Titanium dioxide nanoparticles  | Titanium dioxide NPs via oral exposure lead to locomotor activity in adult mice. |
| AgNPs  | Trolox potentiated oxidative stress in rats following exposure to AgNPs. However, AgNPs did not induce oxidative stress by themselves in the brain. |
| AuNPs  | AuNPs induced dose-dependent cytotoxicity in human neural progenitor cells and rat brains. |
| Lung | MOx NPs  | Toxicities of four different types of MOx NPs (ZnO, SiO2 , TiO2 , and CeO2 ) in human bronchial epithelial cells. |
| AgNPs  | The low dose of AgNPs induced early and long-lasting histological and ultrastructural alterations in rats. |
| AgNP  | Toxicity mediated by small AgNP (≤20 nm) in lung cells depends not only on the particle internalisation level but also on AgNP size and concentration, which may involve varying pathways as targets. |
| AgNP  | Low-dose AgNP exposure induced histological and ultrastructural alterations in rats’ lungs. |
| AuNPs  | Single, as well as aggregated AuNPs, show similar translocation rates across the lung barrier model. |
| ZnONPs  | High-dose (25 µg/mL) ZnO NPs caused severe cytotoxicity. |
| Heart | CdSe/ZnS Quantum dots  | Quantum dots might build up in the heart and induce some biochemical indicators. The consequence alternated and caused oxidative damage and cardiotoxicity. |
| Liver | CeO2NP  | Iron oxide NPs aggravate hepatic steatosis and liver injury. |
| Iron oxide NP  | Hepatotoxicity of graphene oxide in Wistar rats. |
| Graphene oxide  | AuNPs induced species-specific differences in their biodistribution, excretion, and potential for toxicity |
| AuNP  | AuNPs caused granulomas to develop in the mice’s livers and transiently increased serum levels of the pro-inflammatory cytokine interleukin-18. |
| AgNPs  | AgNPs intoxicated the liver by elevating the liver function markers and decreasing serum levels of albumin and total proteins. It also disturbed oxidation homeostasis and induced apoptotic reactions. |
| AgNP  | AgNPs exhibited a marked elevation in liver DNA damage. |
| AgNP  | The low dose of AgNP-induced hepatotoxicity showed early and long-lasting histological and ultrastructural alterations in male rats |
| AgNP  | In vivo study of silver nanomaterials’ toxicity concerning size. |
| Kidney  | Nano-copper particle | The nano-sized copper particle induced hepatotoxicity and nephrotoxicity in rats. |
| IONP | Surface modifications affect iron oxide NP bio distribution in rats. |
| AgNP  | Single silver nanoparticle instillation induced early and persisting moderate cortical damage in rat kidneys. |
| AgNP  | AgNPs could interact with the anatomical structures of the kidney to induce injury. |
| Reproductive System | Metal oxide NPs (MONPs)  | MONPs may induce ROS overproduction, and oxidative stress, and lead to germ cell toxicity. Eventually, the consequence of the impairment of the male reproductive system. |
| AgNPs  | AgNPs could interact with the anatomical structures of the testis and induce injury. |
| Blood | AuNPs  | Trigger platelet aggregation |
| TiO2NPs Al2O3NPs, Fe2O3NPs  | Aggregated NPs increase oxidative stress and immune response |
| Ag, Fe3O4 , CdSe/ZnS, AuNPs  | Several metallic NPs such as Ag, Fe3O4, CdSe/ZnS, and AuNPs are bio-degradable and produce a high concentration of free radicals that may trigger an inflammatory immune response. |

**Conclusion:**

Nanoscience and nanotechnology are fields of science that are inherently transdisciplinary. With the emergence of new bio-based approaches, biologists need to understand not only the fundamental principles of nanoscience but also the technologies and methods traditionally used to characterize nanomaterials. In recent years, nanoparticles have become significant in many fields such as energy, healthcare, environment, and agriculture due to their remarkable properties. Nanoparticle technologies have great potential in converting poorly soluble, poorly absorbed, and biologically active substances into promising deliverable substances. However, there are concerns regarding the nanotoxicity of nanoparticles, particularly metal nanoparticles. These particles, when taken up, can cause damage to various organs and may also have adverse effects on fetuses or offspring in late-stage development in adults via pregnant mothers. Therefore, despite the many useful applications of nanoparticles, it is essential to consider the health issues associated with their uncontrolled use and emissions into the natural environment. This consideration can help make nanoparticle use more convenient and environmentally friendly.

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