**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. This review aims 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 molecule is usually defined as a  [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 fibres 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.

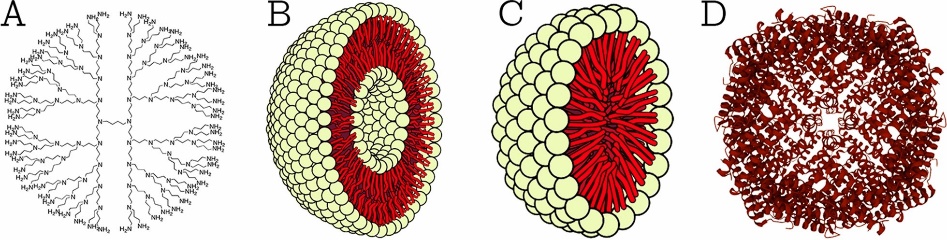
Nanoparticles are typically distinguished from [microparticles](https://en.wikipedia.org/wiki/Microparticle) (1-1000 µm), "fine particles" (sized between 100 and 2500 nm), and "coarse particles" (ranging from 2500 to 10,000 nm), because their smaller size drives very different physical or chemical properties,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

**Classification:**

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

**Organic NPs**

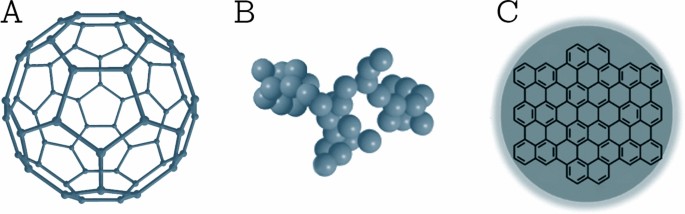
This class -encompasses NPs that are made of proteins, carbohydrates, lipids, polymers, or any other organic compounds. The most prominent examples of this class are dendrimers, liposomes, micelles, and protein complexes such as ferritin (shown in Fig. below). These NPs are typically non-toxic, bio-degradable, and can in some cases, e.g., for liposomes, have a hollow core. Organic NPs are susceptible to thermal and electromagnetic radiation such as heat and light. In addition, they are habitually formed by non-covalent intermolecular interactions, which makes them more imbalanced in nature and bids a route for authorization from the body. Diverse parameters regulate the probable 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 encompasses NPs that are made uniquely from carbon atoms. Some examples of this class are fullerenes, carbon black NPs, and carbon quantum dots (shown in Fig. below). Fullerenes are carbon based molecules that are categorized 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 masses of highly fused sphere-shaped molecules. Carbon quantum dots consist of distinct, quasi-sphere-shaped 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 exclusive electrical conductivity, high strength, electron affinity, optical, thermal, and sorption properties, carbon-based NPs are used in an extensive range of applications 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 multifaceted, carbon-based NPs. Due to their distinctive low toxicity and biocompatibility, they are utilized 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 consists of carbon or organic materials. The typical examples of this category are metal, ceramic, and semiconductor NPs. Metal NPs are virtuously made of metal precursors, they can be monometallic, bimetallic, or polymetallic. Bimetallic NPs can be created from alloys or designed in different layers (core–shell). Due to the limited surface plasmon resonance features, these NPs possess unique optical and electrical properties. In addition, some metal NPs also own exceptional thermal, magnetic, and biological belongings. This makes them increasingly important materials for the development of nanodevices that can be used in numerous physical, chemical, biological, biomedical, and pharmaceutical.

Semiconductor NPs are built of semiconductor materials, which own properties between metals and non-metals. These NPs have exclusive widespread bandgaps and show important alterations in their properties with bandgap tuning related to bulk semiconductor materials. As a consequence, these NPs are significant constituents in photocatalysis, optic, and electronic objects. Ceramic NPs are inorganic objects made of carbonates, carbides, phosphates, and oxides of metals and metalloids, such as titanium and calcium. They are usually manufactured via heat and successive cooling and they can be found in amorphous, polycrystalline, dense, porous or hollow forms. They are chiefly used in biomedical applications due to their high stability and high load capacity. However, 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:**

The biosynthesis of nanoparticles by microorganisms is a green and eco-friendly technology. Diverse microorganisms, both prokaryotes and eukaryotes are used for the 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 conferring to the place of nanoparticles.

**Physical Vapour Deposition**:

This method usually involves the use of materials of interest as sources of evaporation. An inert gas or reactive gas for impacts with material vapour. All the procedures are carried out in a vacuum chamber so that the anticipated purity of the end product can be gained. Generally, high vapour-pressure metal oxides are evaporated from filaments of refractory metals like W, Ta, and Mo in which the materials to be evaporated are held. The concentration of the dispersed material close to the source is high and particle size is small (5nm) such constituents would prefer to acquire a stable lower energy state. Due to small particle–particle interaction bigger constituents can be formed. Hence, they should be detached away from the source as fast as possible. This is done by driving an inert gas near the source, which eliminates the particles from the vicinity of the source. In general, the rate of fading and the pressure of gases inside the chamber control the particle size. Evaporated atoms and gatherings tend to collide with gas molecules and make larger particles, which abbreviate on cold fingers. While moving away from the 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 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. The size, and shape of the evaporated material can depend upon the gas pressure in the 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 the laser beam of high power. The setup is a high vacuum system equipped with an inert gas introduction facility and laser beam. Clusters of any material of which a solid target can be made are possible to synthesize. The laser which gives UV wavelength such as excimer laser is required as other wavelengths like IR or visible are often reflected by some of the metal surfaces. A powerful beam of laser evaporates the atoms from a solid source and atoms collide 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) are typically created by this method.

**Chemical Methods**

**A. Colloids synthesis:**

These are the phase-separated sub-micrometre particles in the form of spherical particles, rods, tubes and plates etc. These are the elements suspended in some hot matrix. Metal, alloy, semiconductor and insulator of diverse sizes and shapes can be created in aqueous or non-aqueous medium. The 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 facility to add some precursors, and gases as well as measure temperature, pH etc; during the reaction. It is likely to eliminate the products at appropriate time intervals. The reaction is carried out under an inert atmosphere to avoid any uncontrolled oxidation of the products.

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

This process is done by the reduction of some metal salt or acid.For instance, copper particles can be attained 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). Similarly, Silver, Gold, Palladium and a few other metal nanoparticlescan be produced by means of appropriate progenitor,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 subclass of colloids. Gels are unremitting network of particles with openings filled with liquid. A sol-gel process involves the 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 includes hydrolysis of precursors, condensation tailed by polycondensation to form molecules, and gelation and drying procedure by various routes. Precursors are to be chosen so that they tend to form gels. Both alkoxides and metal salts can be used. It is also likely to produce nanoparticles like nanorods, nanotubes etc. by sol-gel technique.

**Biological Methods**

**A. Synthesis using Plant Extracts:**

The use of plants in the synthesis of nanoparticles is quite a less studied area as compared to the use of microorganisms to produce nanoparticles. There are a few examples that suggest that plant extracts can be used in the synthesis of nanoparticles. Getting gold nanoparticles from geranium plant extract is done by finely crushed leaves are put in an Erlenmeyer flask and boiling in water just for a minute. Leaves get ruptured and cells release intracellular material.

The solution is cooled and decanted. This solution is added to HAuCl4 aqueous solution, and nanoparticles of gold start forming within 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 mixed to the desired medium like water, ethanol, propanol, etc. and the reaction is carried out in a glass flask with the facility to purge the solution and flow with an inert gas like nitrogen. After the addition of DNA, 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 surfaces. DNA probably bends through its negatively charged phosphate group to the positively charged (Cd+) nanoparticles' surface. The other end of DNA is free to interact with suitable proteins. Nanoparticles prepared in this way are used as sensors of proteins.

**Intracellular synthesis of nanoparticles by fungi:**

This method includes the passage of ions into microbial cells to form nanoparticles in the occurrence of enzymes. In comparison to the size of extracellularly decreased nanoparticles, the nanoparticles moulded inside the organism are smaller. The size limit is undoubtedly related to the constituents nucleating inside the organisms"

**Extracellular synthesis of nanoparticles by fungi:**

Extracellular production of nanoparticles has more usage as compared to intracellular production since it is annulled of unnecessary contiguous cellular components from the cell. Mostly, fungi are known to yield nanoparticles outside the cell because of their massive secretory machinery, which is involved in the reduction and capping of nanoparticles.

**Microbes for the production of nanoparticles:**

Both unicellular and multicellular organisms yield inorganic materials either intra- or extracellularly. The capability of microorganisms like bacteria and fungi to regulate the production of metallic nanoparticles is employed in the exploration for new materials.

**Applications:**

**Nanoparticle applications as nanocomposites:**

In spite of the complications with production, the use of nanomaterials grew distinctly in the early 21st century, with particularly hasty growth in the use of nanocomposites. Nanocomposites were hired in the development and strategies of new constituents, serving, for example, as the building blocks for new [dielectric](https://www.britannica.com/science/dielectric) (insulating) and magnetic resources.

**Food packaging**

Nanoparticles have been gradually combined into food packaging to regulate the ambient atmosphere around food, keeping it fresh and safe from microbial adulteration. Such composites use nanoflakes of [clays](https://www.britannica.com/science/clay-mineral) and claylike molecules, which slow down the [access](https://www.britannica.com/dictionary/ingress) to moisture and decrease gas transport across the packaging film. It is also possible to incorporate nanoparticles with apparent antimicrobial effects (e.g., nano copper 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 areas of food preparation.

**Flame retardants**

Nanoparticles were discovered for their potential to substitute extras built 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 nano clays and hydroxide nanoparticles were associated with fewer emissions of harmful fumes than products containing certain other types of additives.

**Batteries and supercapacitors**

The capability to make nanocomposite materials to have extreme internal exterior areas for packing [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 particularly valued for use in [batteries](https://www.britannica.com/technology/battery-electronics) and supercapacitors. Indeed, nanocomposite molecules have been manufactured for numerous applications linking [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-standing motive in [materials science](https://www.britannica.com/technology/materials-science) had been to alter [ceramics](https://www.britannica.com/technology/ceramic-composition-and-properties) that are hard and predisposed to cracking into rougher, more [strong](https://www.merriam-webster.com/dictionary/resilient) materials. By the early 21st century, researchers had accomplished that goal by integrating an active blend of nanoparticles into ceramics materials. Further new ceramics constituents that were under progress comprised all-ceramic or polymer-ceramic assortments, which shared the exclusive functional (e.g., electrical, magnetic, or mechanical) belongings of a nanocomposite constituents with the belongings of ceramics materials.

**Light control**

In the 1990s the progress of blue light-emitting diodes ([LEDs](https://www.britannica.com/technology/LED)), had the capacity to harvest 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 transported about a need for composite constituents that could be used to hide the [diodes](https://www.britannica.com/technology/diode) to alter blue light into other [wavelengths](https://www.britannica.com/science/wavelength) (such as red, yellow, or green) to attain white light. One way of procuring the desired light is by leveraging the size or [quantum](https://www.britannica.com/science/quantum) effect of small semiconducting the constituent part. 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 alteration in the above cases is accomplished with submicron constituent part of inorganic phosphor constituents united into the [polymer](https://www.britannica.com/science/polymer).

**Nanoparticle applications in medicine**

The minuteness of nanoparticles is particularly beneficial in medicine; nanoparticles can not only move widely all over the body but also enter [cells](https://www.britannica.com/science/cell-biology) or be intended to bind to specific cells. Those properties have enabled new ways of [attracting](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 contaminated [tissues](https://www.britannica.com/science/tissue) in the body. They also have [enabled](https://www.merriam-webster.com/dictionary/facilitated) the growth of new approaches of delivering therapy, such as by giving local heating (hyperthermia), blocking vasculature to unhealthy tissues and tumours, or 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 toil by misusing the change in contrast carried about by tiny units of superparamagnetic iron [oxide](https://www.britannica.com/science/oxide) in [magnetic resonance imaging](https://www.britannica.com/science/magnetic-resonance-imaging) (MRI). Such constituent parts also can be used to destroy tumours via hyperthermia, in which an irregular [magnetic field](https://www.britannica.com/science/magnetic-field) reasons them to heat and abolish tissue on a local scale.

Nanoparticles can be premeditated to [improve](https://www.merriam-webster.com/dictionary/enhance) fluorescent imaging or to improve images from [positron emission tomography](https://www.britannica.com/topic/positron-emission-tomography) (PET) or [ultrasound](https://www.britannica.com/science/ultrasound). Those methods characteristically require that the nanoparticle be able to distinguish a particular cell or disease state. In theory, the same idea of targeting could be used in assisting the precise delivery of a drug to a given disease site. The drug could be approved via a nanocapsule or a liposome, or it could be approved in a porous nanosponge conformation and then held by bonds at the targeted site, thereby allowing the slow release of the drug. The growth of nanoparticles to relief in the delivery of a drug to the [brain](https://www.britannica.com/science/brain) via inhalation holds significant promise for the [treatment](https://www.britannica.com/dictionary/treatment) of neurological disorders such as [Parkinson's](https://www.britannica.com/science/Parkinson-disease), [Alzheimer's](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 normal constituent of bone, used in blend with [collagen](https://www.britannica.com/science/collagen) or collagen alternatives could be used in future tissue-repair therapies.

Nanoparticles also have been used in the growth 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 to develop 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 capacity to damage skin cells and [DNA](https://www.britannica.com/science/DNA) (deoxyribonucleic acid). Scientists proceeded to grow a nanoparticle form of titanium oxide that confined a slight amount of [manganese](https://www.britannica.com/science/manganese). Studies indicated that nanoparticle-based sunscreen was safer than sunscreen products manufactured by using traditional materials. The safety enhancement was attributed to the overview of manganese, which altered the semiconducting belongings of the compound from n-type to p-type, thus shifting its [Fermi level](https://www.britannica.com/science/Fermi-level), or oxidation-reduction belongings, 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 biodistribution 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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