A Review On – Nanoparticles

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Abstact :

Nanoparticle are at the leading edge of the rapidly developing field of nanotechnology. Their unique size-dependent properties make these materials superior and indispensable in many areas of human activity. This brief review tries to summarise the most recent developments in the field of applied nanomaterials, in particular their application in biology and medicine, and discusses their commercialisation prospects.

The special mechanical properties of nanoparticles allow for novel applications in many fields, e.g., surface engineering. In this review, the basic physics of the relevant interfacial forces to nanoparticles and the main measuring techniques are briefly introduced first. Then, the theories and important results of the mechanical properties between nanoparticles or the nanoparticles acting on a surface, e.g., hardness, elastic modulus, adhesion and friction, as well as movement laws are surveyed. Afterwards, several of the main applications of nanoparticles as a result of their special mechanical properties, including lubricant additives, nanoparticles in nanomanufacturing and nanoparticle reinforced composite coating, are introduced. A brief summary and the future outlook are also given in the final part.

Keywords: Nanoparticles, engineering Adhesion, Properties ,Mechanical ,Application

Introduction :

Nanotechnology refers to the research and technological developments at atomic, molecular, and macromolecular scales, which lead to the controlled manipulation and study of structures and devices with length scales in the range of 1–100 nm.[1] Nanotechnology, the term probably first coined by Taniguchi in Japan [2] is a branch of manufacturing where dimensions on the order of a nanometer are important. Several researchers emphasized the significance of size and revealed the advantages of nanoparticles over microspheres . Biological nanoparticles are mainly developed for drug delivery systems as an alternative to liposome technology, in order to overcome the problems related to the stability of these vesicles in biological fluids and during storage . The nanoparticle technology used in the recent years has great significance in improving the efficacy of the drugs. The nanoparticles fit into colloidal drug delivery systems, which offer advantages of drug targeting by modified body distribution [3].

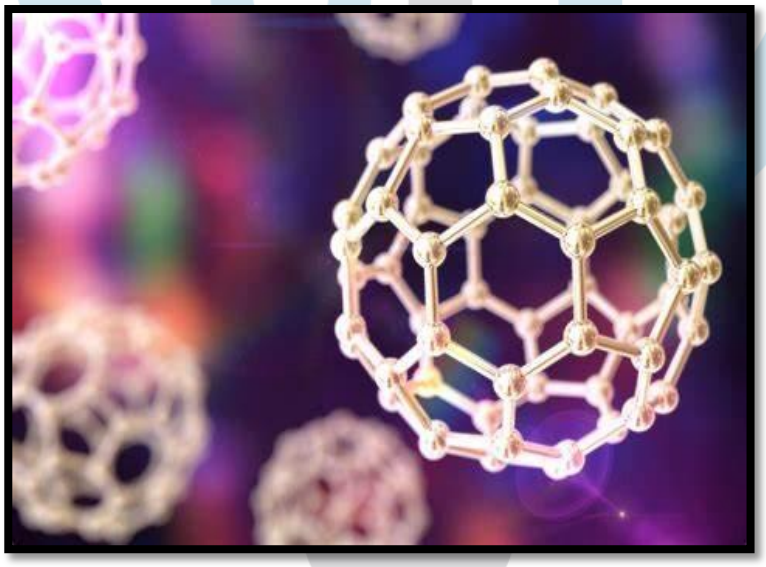


Fig. 1: Nanoparticles

Manufactured nanoparticles are defined as particulate substances of nanoscale dimensions (usually <100 nm). In atmospheric science particles <100 nm have been called ultrafine particles and most atmospheric nanoparticles are usually <50 nm. It has been shown that the particle-count distribution peaks at 20–30 nm at roadsides with heavy traffic . Environmental or atmospheric nanoparticles contain semi-volatile alkanes that originate from fuels and lubricants whereas components of manufactured or engineered nanoparticles vary, depending on the type of product. It should be noted that nanoparticles are also used in drug-delivery systems (DDS), because nanoparticles can evade phagocytosis and efficiently reach the target points.[4]

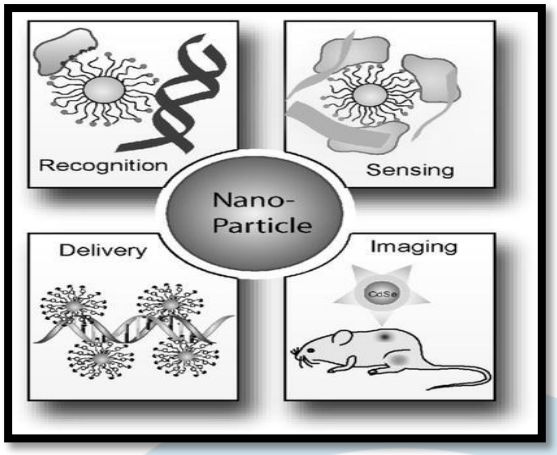


Fig .2: Uses of nanoparticles

Classification of nanoparticles :

1. Organic nanoparticles
2. Inorganic nanoparticles
   - Metal based
   - Metal oxides based
3. Carbon based
   - Fullerenes
   - Graphene
   - Carbon Nano Tubes
   - Carbon Nanofiber
   - Carbon black [5]

1. Organic nanoparticles:

Dendrimers, micelles, liposomes and ferritin, etc. are commonly knows the organic nanoparticles or polymers. These nanoparticles are biodegradable, non-toxic, and some particles such as micelles and liposomes has a hollow core (Figure1), also known as nanocapsules and are sensitive to thermal and electromagnetic radiation such as heat and light [6]. These unique characteristics makes them an ideal choice for drug delivery. The drug carrying capacity, its stability and delivery systems, either entrapped drug or adsorbed drug system determines their field of applications and their efficiency apart from their normal characteristics such as the size, composition, surface morphology, etc. The organic nanoparticles are most widely used in the biomedical field for example drug delivery system as they are efficient and also can be injected on specific parts of the body that is also known as targeted drug delivery.

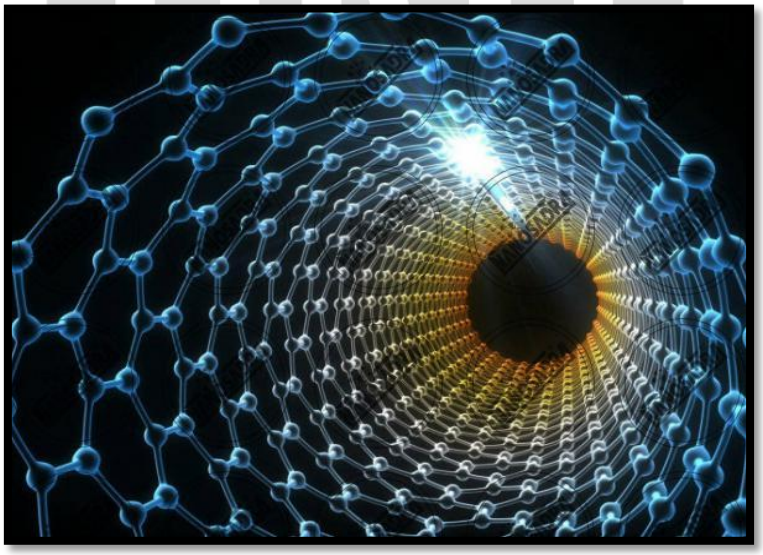


Fig.3: organic nanoparticles

2. Inorganic nanoparticles :

Inorganic nanoparticles are particles that are not made up of carbon. Metal and metal oxide based nanoparticles are generally categorised as inorganic nanoparticles.

- **Metal based:**

Inorganic nanoparticles are particles that are not made up of carbon. Metal and metal oxide based nanoparticles are generally categorised as inorganic nanoparticles.[7] The commonly used metals for nanoparticle synthesis are aluminium (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag) and zinc (Zn).

- **Metal oxides based:**

The metal oxide based nanoparticles are synthesised to modify the properties of their respective metal based nanoparticles, for example nanoparticles of iron (Fe) instantly oxidises to iron oxide (Fe_2O_3) in the presence of oxygen at room temperature that increases its reactivity compared to iron nanoparticles. Metal oxide nanoparticles are synthesised mainly due to their increased reactivity and efficiency.[8]

- **Carbon based:**
  The nanoparticles made completely of carbon are knows as carbon based [9]. They can be classified into fullerenes, graphene, carbon nano tubes (CNT), carbon nanofibers and carbon black and sometimes activated carbon in nano size.
- **Fullerenes:**
  Fullerenes (C_{60}) is a carbon molecule that is spherical in shape and made up of carbon atoms held together by sp^2 hybridization. About 28 to 1500 carbon atoms forms the spherical structure with diameters up to 8.2 nm for a single layer and 4 to 36 nm for multi-layered fullerenes.
- **Carbon Nano Tubes:**

Carbon Nano Tubes (CNT), a graphene nanofoil with a honeycomb lattice of carbon atoms is wound into hollow cylinders to form nanotubes of diameters as low as 0.7 nm for a single layered and 100 nm for multi-layered CNT and length varying from a few micrometres to several millimetres. The ends can either be hollow or closed by a half fullerene molecule.

- **Carbon Nanofiber**

The same graphene nanofoils are used to produce carbon nanofiber as CNT but wound into a cone or cup shape instead of a regular cylindrical tubes.

Carbon black:

An amorphous material made up of carbon, generally spherical in shape with diameters from 20 to 70 nm. The interaction between the particles are so high that they bound in aggregates and around 500 nm agglomerates are formed.[10]

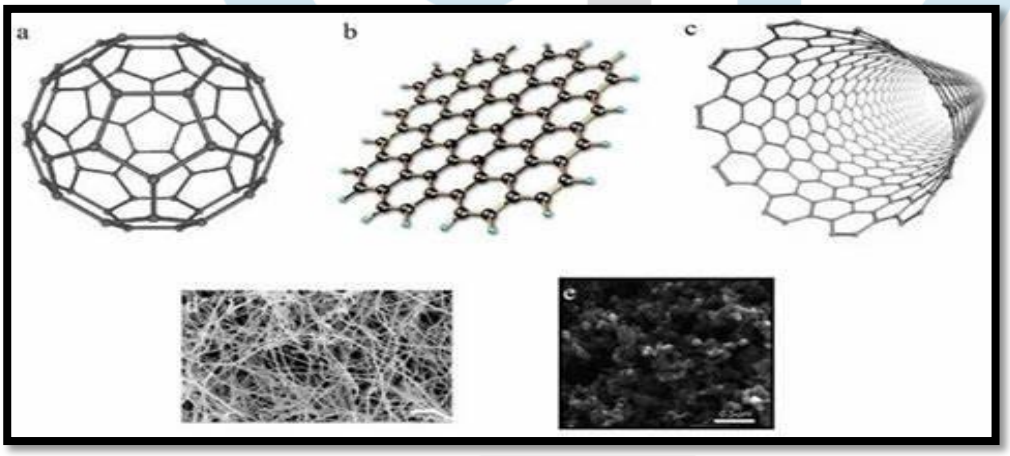


Fig: Carbon based nanoparticles: a – fullerenes, b – graphene, c – carbon nanotubes, d – carbon nanofibers and e – carbon black

Properties of nanoparticle:

1] Van der waals [vdW] force
2] Electrostatic force and electrical double layer (EDL) force
3] Capillary force

1. Van der Waals (vdW) forces:

VdW forces are the weak interaction between all molecules and particles, which play important roles in the particles' mechanical properties. This kind of force includes three parts: one is the orientation force resulting from the interaction between the permanent dipole moment of polar molecules. The second is the induction force which comes from the interaction between the permanent dipole moment of the polar molecule and the induced dipole moment. The third is the dispersion force (the London

force) which exists in a wide variety of polar and nonpolar molecules, coming from the induced instantaneous dipole polarization. VdW energies are usually from several to dozens of thousands of Joules per mole, one or two orders of magnitude smaller than the chemical bond energy. The vdW forces are long-range forces and can be effective in a large range of distances, varying from long distances greater than 10 nm down to atomic scale distance (about 0.2 nm) [26]

2. Electrostatic force and electrical double layer (EDL) force:

For particles suspended in water or any liquid with a high dielectric constant, they are usually charged and can be prevented from coalescing due to the repulsive electrostatic force. The charging of a surface in a liquid has three main sources [29]: (1) the ionization or dissociation of surface groups; (2) the adsorption or binding of ions from the solution onto a previously uncharged surface; (3) when two dissimilar surfaces are very close, charges can hop across from one surface to the other. The surface charges are balanced by an oppositely charged ion layer in the solution at some distance away from surface, forming the EDL.

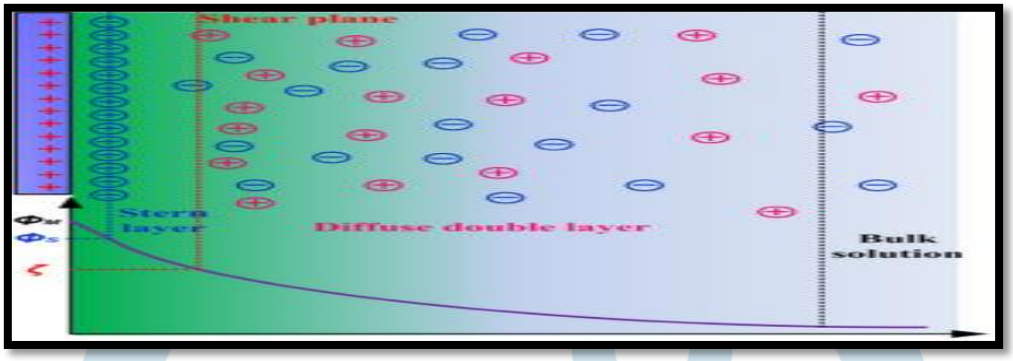


Fig 5. Schematic model of EDL

3. Capillary force:

Capillary force is mainly due to the formation of liquid menisci (also termed the meniscus force), the significance of which was realized by Haines and Fisher. Capillary force can be classified into two types: normal capillary force and lateral capillary force. A comprehensive review of the normal capillary force was given by Butt and Nagayama contributed a lot to the study of the structure of colloid nanoparticles due to the lateral capillary force. Capillary forces should be considered in the studies on powders, soils and granular materials , the adhesion between particles or particles to surfaces and the stiction in micro/nano-electromechanical systems . It is also relevant to nanoparticle assembling or living cells selfassemble technologies [28].

Synthesis of Nanoparticles:

The nanoparticles are synthesised by various methods that are categorised into bottom-up or top-down method. A simplified representation of the process is presented in Figure.[10]

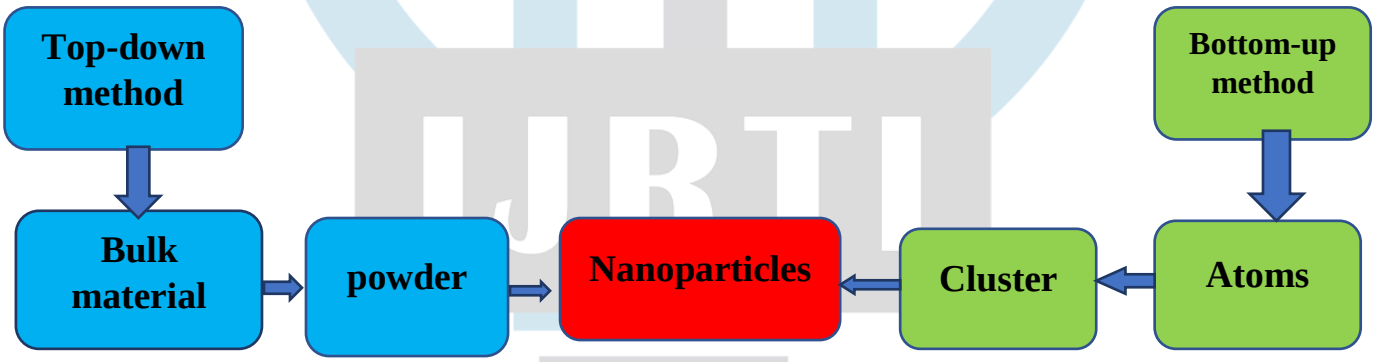
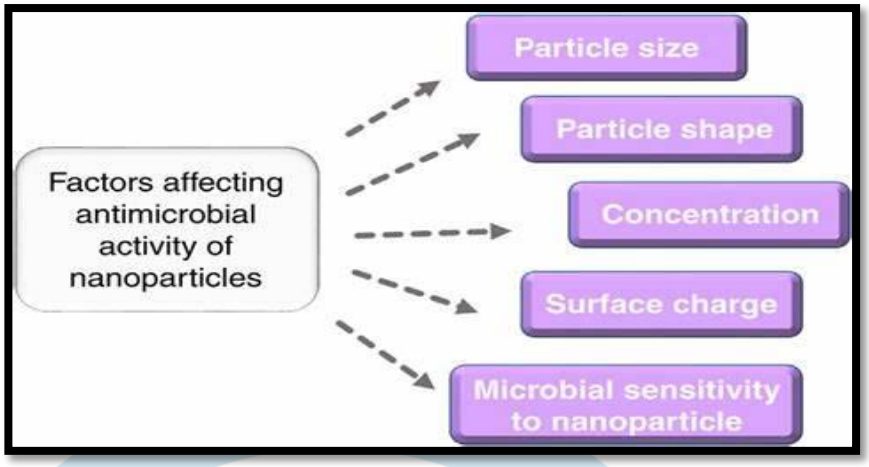


Fig .6: Synthesis of nanoparticles



Factors affecting nanoparticles:

1. **Effect of Size**
2. **Effect of the Core**
3. **Effect of Surface Functionality and Charge**
4. **Effect of Active Targeting [11]**

1. Effect of size :

On the basis of physiological parameters such as hepatic filtration, tissue extravasation, tissue diffusion, and kidney excretion, it is clear that, along with surface composition, particle size is a key factor in the biodistribution of long-circulating nanoparticles and achieving therapeutic efficacy. In one study, in vivo biodistribution results of polystyrene nanoparticles with consistent composition and varying particle sizes of 50 and 500 nm showed higher levels of agglomeration of the larger nanoparticles in the liver. It was suggested that the mechanism of hepatic uptake was mediated by surface absorption of proteins leading to opsonization. However, the effect of temperature (37 °C vs 4 °C) on hepatic elimination showed unexpectedly faster uptake of the 50 nm polystyrene nanoparticles at the lower temperature. Similarly, the size of the nanoparticle was shown to have a substantial effect on the protein absorption.[12] Small (200 nm) pegylated PHDCA nanoparticles incubated with serum protein for 2 h showed a significant correlation between particle size and protein absorption.[13]

2. Effect of core:

Shenoy et.al.[14] investigated the biodistribution of stealth poly(-amino ester) nanoparticles (PbAE) and poly(caprolactone) (PCL)-based nanoparticles with a similar size range of 100-200 nm. In addition, both nanoparticle formulations had a very high positive surface charge of approximately +30 mV. The results clearly showed a significantly higher level of accumulation in the heart and lung tissues for the PbAE nanoparticles. This was correlated with a lower level of accumulation in the liver as compared to PCL nanoparticles. It was suggested that a higher degree of aggregation of PbAE nanoparticles in the presence of serum proteins affected the biodistribution leading, to such high levels of accumulation in the lung. Recently, greater degrees of nanoparticle “flexibility” were hypothesized to improve the binding ability of particles on the cell surface.[15] Shell cross-linked nanoparticles (SCKs) containing partially hydrochlorinated poly(isoprene) cores were shown to undergo temperature-dependent deformation.[15]

3. Effect of Surface Functionality and Charge:

It has been established that the physicochemical characteristics of a polymeric nanoparticle such as surface charge and functional groups can affect its uptake by the cells of the phagocytic system. It was previously shown that polystyrene microparticles with a primary amine at the surface underwent significantly more phagocytosis as compared to microparticles having sulfate, hydroxyl, and carboxyl groups. Therefore, it is well accepted that positively charged nanoparticles have a higher rate of cell uptake compared to neutral or negatively charged formulations.

Nanoparticles carrying a positively charged surface are also expected to have a high nonspecific internalization rate and short blood circulation half-life. Nanoshells having a negative surface charge have shown a marked reduction in the rate of uptake. The potential for nanoshells with BSA absorbed on the surface of the nanoparticle was characterized by a shift to a more negative value.[16] However, the BSA absorption did not promote a higher rate of cell uptake. Interestingly, when the biodistribution of Tyr- and Tyr-Glu-PEG/PDLLA micelles was investigated in mice, both the Tyr- (neutral) and TyrGlu (negatively charged) PEG/PDLLA micelles exhibited no remarkable difference in their blood clearance kinetics.[17]

4. Effect of Active Targeting:

Active targeting of nanoparticles involves the conjugation of targeting ligands to the surface of nanoparticles. These ligands can include antibodies, engineered antibody fragments, proteins, peptides, small molecules, and aptamers. The active targeting mechanism takes advantage of highly specific interactions between the targeting ligand and certain tissues or cells within the body to promote the accumulation of nanoparticles In the case of weak binding ligands, low affinity can be offset by increased avidity through the surface functionalization of multiple molecules or multivalent designs and has been shown to be a valid approach. There are several examples of FDA-approved antibodies in clinical practice today, including Rituxan (target, CD20-positive B-cells for the treatment of non-Hodgkin’s lymphoma and rheumatoid arthritis), Herceptin (target, HER-2-overexpressing breast cancer cells), Erbitux [target, epidermal growth factor receptor (EGFR) for the treatment of colorectal cancer], Iressa (target, EGFR for the treatment of non-small cell lung cancer and metastatic breast cancer), and Avastin [target,

vascular epidermal growth factor (VEGF) for the treatment of metastatic colorectal, non-small lung, and breast cancers]. While the progress with monoclocal antibodies has been encouraging, they have not been shown to be curative.[17]

Advantages of nanoparticles:

1. Particle size and surface characterstics of nanoparticles can be easily manipulated to achieve both passive and active drug targeting after parenteral administration .
2. They control and sustain release of the drug during the transportation and at the site of localization
3. Subsequetent clearance of the drug so as to acheive increase in drug therapeutic efficacy and reduction in side effect .
4. Drug loading is relatively high and drug can be incorporated into the systems without chemical reaction
5. Site – specific targeting can be achieved by attaching targeting ligands to surface of particles .
6. The system can be used for various route of administration including oral, nasal, parenteral, intra cellular etc.
7. Nanoparticles can help reverse tissue damage and improve healing processes because the proteins have properties that aid in cellular communication, as well as promote tissue growth. Strength sports athletes and people that commit to developing their physiques would benefit as a result.
8. "When you think about athletes and the stress that they are placing on their muscles and joints, some of them are being diagnosed with osteoarthritis at very young ages. Nanoparticles can actually repair and restore injured areas, and treat the underlying issue''
9. Many nerve issues are caused by initial trauma or inflammation without ever fully being repaired," explained Adair. "These treatments can help do that."
10. Outside of underlying health issues, Adair also shared that people that are focusing on anti-aging or addressing aesthetic concerns such as wrinkles or sunspots, hair loss, and sagging skin can also see results from nanoparticles.

Disadvantages of nanoparticles:

1. Small size and large surface area can lead to particle aggregation .
2. Physical handling of nanoparticles is difficult in liquid and dry form .
3. Limited drug loading .
4. Toxic metabolite may form.
5. Polymeric nanoparticles posses limited drug loading capacity.
6. On reapeated administration ,toxic metabolite may be formed during the biotrasformation of polymeric carrier .
7. The polymeric nanoparticles are relatively slowly biodegradable which might cause systemic toxicity.

Applications of nanoparticles in biology and medicine:

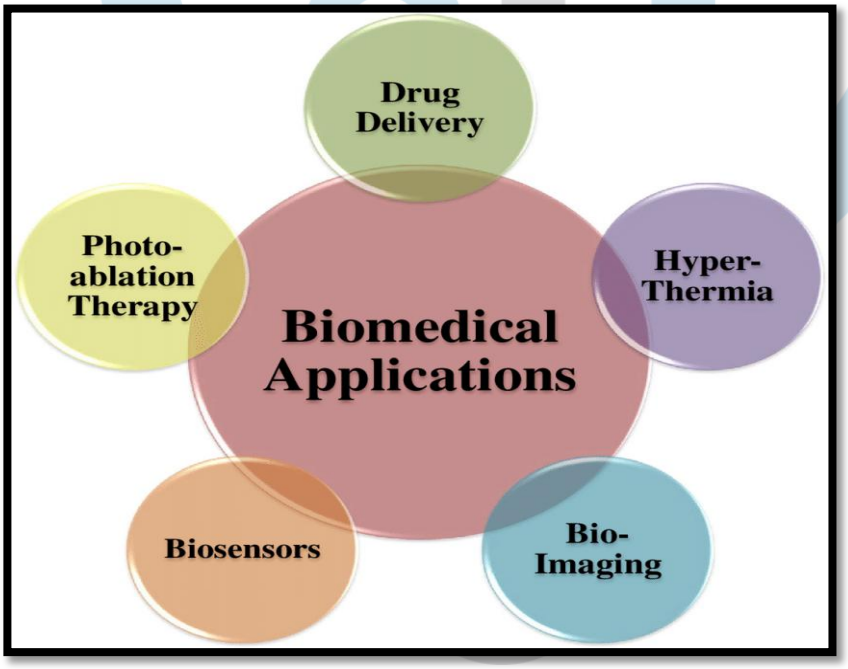


Fig.7: Application of Nanoparticles

1. Nanoparticles in Biosensing:

The sensing of biological agents, diseases, and toxic materials is an important goal for biomedical diagnosis, forensic analysis, and environmental monitoring. A sensor generally consists of two components: a recognition element for target binding and a transduction element for signaling the binding event. The unique physicochemical properties of NPs coupled with the inherent increase in signal-to-noise ratio provided by miniaturization makes these systems promising candidates for sensing applications. As an example, gold nanoparticles exhibits unique optical and electronic properties based on size and shape.

Based on the similar approach a highly selective and sensitive lead (Pb2þ) biosensor was reported by Lu et al. In their sensor design, they used a Pb2þ -specific ''DNAzyme'for the colorimetric detection of proteins.'[18]

2. Colorimetric Sensing:

The oligonucleotide-mediated nanoparticle aggregation process has been extensively used for the development of for the colorimetric detection of proteins. The bivalent lectin agglutinin specifically recognizes b-D-galactose, inducing the aggregation of galactose-functionalized nanoparticles at 1 ppm. Other glyconanoparticles have been used for sensing various proteins such as Concanavalin A and cholera toxin.[19]

3. Fluorescence Sensing:

The exceptional quenching ability of metallic nanoparticles makes them excellent materials for Fo¨rster resonance energy transfer (FRET)-based biosensors, for example, for the fabrication of molecular beacons for sensing DNA. In this approach, the dye molecule is close to the nanoparticle surface in the absence of the target DNA strand due to hairpin structure of the attached DNA, resulting in fluorescence quenching . Hybridization of the target DNA opens up the hairpin structure, resulting in a significant increase in composed of a catalytic and a substrate strand.[19]

4. Electrochemical Sensing:

The conductivity and catalytic properties of metallic and semiconductor nanoparticles have been applied to electroanalytical sensing.[84] The attachment of nanoparticles onto electrodes drastically enhances the conductivity and electron transfer from the redox analytes. Based on this concept, Willner et al. reported several systems using nanoparticle– enzyme hybrids as electrochemical sensors. In one example, a bioelectrocatalytic system was constructed by connecting the redox enzyme glucose oxidase onto a gold nanoparticle that was functionalized with N6 -(2-aminoethyl) flavin adenine (FAD) (Fig. 9a).[86] This enzyme–nanoparticle hybrid system was linked to the electrode through dithiols, or alternatively the FAD-functionalized nanoparticle was assembled onto the electrode followed by the addition of apo-GOx. This system exhibited a highly efficient electrical communication with the enhanced turnover rates as compared to native Gox, and provided an effective sensor for glucose in the physiological concentration regime.

5. Other Sensing Methods:

Surface enhanced Raman scattering (SERS) has been successfully exploited in biological sensing using nanoparticles.Mirkin et al. used gold nanoparticles labeled with oligonucleotides and Raman-active dyes to achieve multiplexed detection of different DNA targets.[92] The SERS method was also employed for the detection of the protein–small molecule and protein–protein interactions by fabricating the nanoparticles with proteins and Raman dyes. In this aspect nanoparticles can be used as a potential DDS owing to their advantageous characteristics, as mentioned previously. As an example of cellular delivery, mixed monolayer protected gold clusters were exploited for in vitro delivery of a hydrophobic fluorophore (BODIPY); an analog of hydrophobic drugs.[20]

6. Tissue engineering:

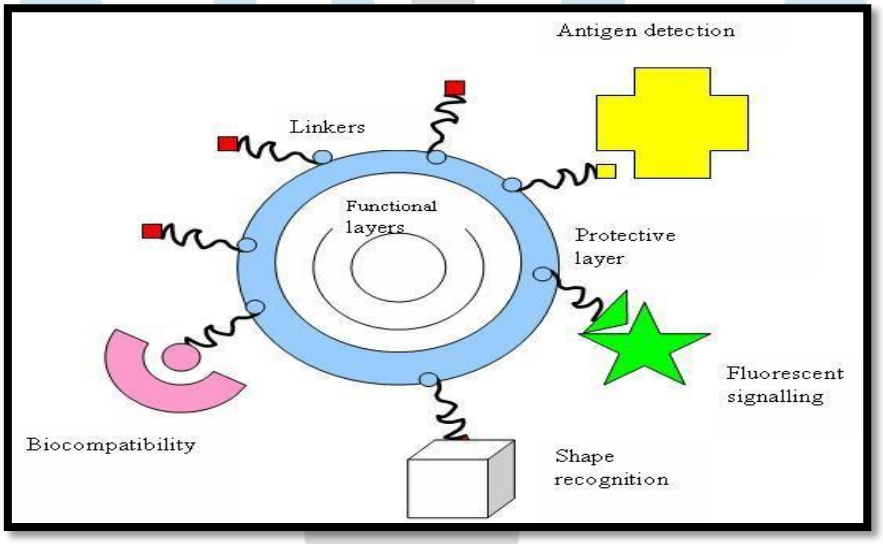


Fig.8: Typical configurations utilised in nano-bio materials applied to medical or biological problems.

Natural bone surface is quite often contains features that are about 100 nm across. If the surface of an artificial bone implant were left smooth, the body would try to reject it. Because of that smooth surface is likely to cause production of a fibrous tissue covering the surface of the implant. This layer reduces the bone-implant contact, which may result in loosening of the implant and further inflammation. It was demonstrated that by creating nano-sized features on the surface of the hip or knee prosthesis one could reduce the chances of rejection as well as to stimulate the production of osteoblasts. The osteoblasts are the cells responsible for the growth of the bone matrix and are found on the advancing surface of the developing bone.

The effect was demonstrated with polymeric, ceramic and, more recently, metal materials. More than 90% of the human bone cells from suspension adhered to the nanostructured metal surface , but only 50% in the control sample. In the end this findings would allow to design a more durable and longer lasting hip or knee replacements and to reduce the chances of the implant getting loose.[21]

7. Protein detection:

Proteins are the important part of the cell's language, machinery and structure, and understanding their functihttps://pubmed.ncbi.nlm.nih.gov/30465498/onalities is extremely important for further progress in human well-being. Gold nanoparticles are widely used in immunohistochemistry to identify protein-protein interaction. However, the multiple simultaneous detection capabilities of this technique are fairly limited. Surface-enhanced Raman scattering spectroscopy is a well-established technique for detection and identification of single dye molecules. By combining both methods in a single nanoparticle probe one can drastically improve the multiplexing capabilities of protein probes.

The group of Prof. Mirkin has designed a sophisticated multifunctional probe that is built around a 13 nm gold nanoparticle. The nanoparticles are coated with hydrophilic oligonucleotides containing a Raman dye at one end and terminally capped with a small molecule recognition element (e.g. biotin). Moreover, this molecule is catalytically active and will be coated with silver in the solution of Ag(I) and hydroquinone. After the probe is attached to a small molecule or an antigen it is designed to detect, the substrate is exposed to silver and hydroquinone solution. A silver-plating is happening close to the Raman dye, which allows for dye signature detection with a standard Raman microscope. Apart from being able to recognise small molecules this probe can be modified to contain antibodies on the surface to recognise proteins. When tested in the protein array format against both small molecules and proteins, the probe has shown no cross-reactivity.[22]

Industrial Applications of Nanoparticles:

Nanoparticle application may best be viewed along material classes: Metals, oxides and polymers have been reviewed earlier, and usually reflect a tight dependence on available preparation methods, i;e. easy accessible materials rapidly caught industrial interest:

1. Particles as chemically inert additives:

Small, chemically inert particles have been prominently used in pigments, polymer fillers and surface finishing next to bulk applications such as ceramics. None of them were traditionally called “nano”, and most scientist are little aware of the rather broad, established use of small particles. Historically most interesting is the use of various carbon soot pigments in cave and pottery paintings and carefully reduced iron oxide colloids as red and yellow pigments.[23]

2. Chemically active particles: Catalysts, biomaterials and antimicrobial additives:

Active surfaces on solids display chemical reactivity that is industrially applied as heterogeneous catalysis. Bioactivity, i.e. the benign interaction with living tissue/cells, is a key condition for biomedical implants and devices. In the case of activity against small organisms, e.g. antimicrobial activity, the inhibition or killing of microorganisms is part of the product definition. In all areas, the surface effect is directly related to particle size for obvious geometric reasons, and smaller particles have become advantageous for their better mass or volume related performance (effect per volume or per mass of material). The academically most advanced active surfaces are part of catalysis, which became a field of research on its own in the mid-20th century. Again, at that time, the term “nano” was not regularly used.

Biomaterials:

The discovery of the nanoparticulate form of minerals in bone and teeth has initiated research on nanostructured biomaterials almost three decades ago. The use of “nano” surface, morphology and architecture continues to fascinate biologists. Orthopedic surgery has been the first to profit from nanoparticulate biomaterials.12 Here, mainly inert or biologically tolerated materials were used for improving healing, implant adhesion and tissue response. Chemically active biomaterials such as bioglass strongly profit from smaller particle size since the improved surface to volume ratio increases the materials activity.13 Particle size enables mobility – a key aspect in transporting or delivering a material to a site of application. As a consequence, this enabled the huge field of nanoparticle-based drug delivery and therapy.[24]

3. Insights from the chemical industry: Cosmetic UV protection and colour filters for LCDs:

- **Replacing traditional pigments:**

Colour in consumer goods is omnipresent. Traditionally, providing colour has been in the hands of inorganic (pigment) chemists or organic synthetic chemists linking structure (e.g. substitution in an indanthrene moiety) to colour information. A new way to look at colour was initiated by the development of quantum dots, small semiconductor particles with size controlled electronic levels and therefore also colour.15 The size dependent optical properties of such particles are a true “nano” effect and can be understood in terms of classical quantum mechanics.[25]

Future aspects:

1. Nano-materials R&D is an increasingly important field globally.
2. Relevant research is also being done to use nanoparticles in chemotherapy so as to have a targeted attack on the tumour and lessen the side effects of chemo on the rest of the body.[29]
3. There are endless possibilities for nanomedicine, ranging from monitoring inflammation and post-surgical recovery to more unusual use cases where electronic devices actually interfere with our body’s signals for controlling organ function.
4. The application of nanotech in the dental field is called nano dentistry.
5. Enhanced bone regeneration.
6. Improvement in medical and casualty care for soldiers.[30]

Conclusion :

Increasingly high requirements of the surface and interface properties of many mechanical systems demand new designs and improvements of surface modifications and manufacturing technologies. Nanoparticles exhibiting many unique mechanical properties have become one of the most attractive choices for meeting these needs in the past couple of years. The foregoing parts review basic physics and recent important results of nanoparticles from the perspectives of their mechanical properties and interfacial interactions, as well as related applications. Available fundamental research data regarding the mechanical properties of nanoparticles provide valuable guidance for their effective implementation in surface engineering, micro/nanomanufacturing and nanofabrication etc. Many of these applications with nanoparticles have already made impressive progress in practice and exhibited significant advantages in many fields.

The development of particles that are nanoscaled has created great apportunities in the development of improved drug delivery system. designing nanoparticles to be taken orally. introduction and improvement of controlled release properties and targeting ligands is expected to enable the development of safer and more effective therapeutic nanoparticles .the development of nanoparticle that are nanoscale has created great apportunities in the improved drug delivery system .

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