Overview

Principles of nanoscience: An overview

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The scientific basis of nanotechnology as envisaged from the first principles is compared to bulk behavior. Development of nanoparticles having controllable physical and electronic properties has opened up possibility of designing artificial solids. Top down and bottom up approaches are emphasized. The role of nanoparticle (quantum dots) application in nanophotonics (photovoltaic cell), and drug delivery vehicle is discussed. Fundamentals of DNA structure as the prime site in bionanotechnological manipulations is also discussed. A summary of presently available devices and applications are presented.

Keywords: Bottom up approach, DNA biotechnology, Nanoparticles, Quantum dot, Top down approach

Introduction

Nanotechnology is now identified as an area related to research and technology development at the atomic, molecular and macromolecular levels. The molecular theory of matter starts with quantum mechanics and statistical mechanics. The first question that comes to mind is how one would be able to brush aside the Heisenberg Uncertainty Principle. The Principle helps determine the size of electron clouds and hence the size of atoms. The mass of the atoms and molecules are quite large and the quantum mechanical calculation by the Heisenberg Uncertainty Principle places no limit on how well atoms and molecules can be held in place. Fenyman's lecture entitled “There’s plenty of room at the bottom—An invitation to enter a new field on physics”, stated that the entire Encyclopedia Britannica could be put on the tip of a needle and in principle, there is no law preventing such an undertaking. In relation to biological structures the nanoparticles are of comparative size and hence their possible mutual interaction is self evident. The particles in the nano range display physical, chemical and biological properties which can be manipulated for the desired objectives. It is predicted that the behavior of the particles at the macro and nano range may be very different and the same material in bulk. Nanostructures and nanomaterials possess a large fraction of surface atoms per unit volume. The ratio of surface atoms to interior atoms changes dramatically if one successively divides a macroscopic object into smaller parts. The total surface energy increases with the overall surface area, which in turn is strongly dependent on the dimension of the material.

Particles of controlled size with at least one dimension less than 100 nm are considered nanoparticles. Nanoparticles with a diameter between one and several tens of nanometers possess an electronic structure that is intermediate of the discrete electronic level of an atom or molecule and the band structure of a bulk material. The resulting size dependent role of physical properties is called the quantum size effect. Depending on their chemical composition, their optical and electronic properties have generated much attention in studies of properties of particles approaching molecular dimensions. At nanometer length scales, the line between colloids and molecules becomes blurred. Nanotechnology is the engineered manipulation of atoms and molecules in a user defined and repeatable manner to build objects with certain desired properties. These nanosize building blocks are intermediate systems in size lying between atoms and small molecules and microscopic and macroscopic system. These building blocks contain a limited and countable number of atoms. They can be synthesized and designed atom by atom. They constitute the means of our entry into new relams of nanoscience and nanotechnology. Molecular Building Blocks (MBBs) are distinguished for their unique properties (e.g. graphite, fullerene molecules made of a number of carbon atoms, e.g. C_{60}, C_{70}, C_{240}, etc).

Specific surface area and thus, the total surface energy are negligible when cubes are large, but become significant for very small particles. When the
particles change from centimeter size to nanometer size, the surface area and the surface energy increase seven orders of magnitude. Nanoparticles to be discussed here are single crystal, polycrystalline and amorphous particles with all possible morphologies, such as spheres, cubes and platelets. In general, the characteristic dimension of the particles is not larger than several hundred nanometers. If the nanoparticles are single crystalline, they are often referred to as nanocrystals.

Due to the vast surface area, all nanostructured materials possess a huge surface energy and thus, become thermodynamically unstable or metastable. The mode of increase in surface area is as depicted in Fig. 1 (a, b). One of the great challenges in fabrication and processing of nanomaterials is to overcome the surface energy and to prevent the nanostructures from growth in size, driven by the reduction of overall surface energy. A major goal of nanotechnology is to manipulate atoms and molecules in bulk to make large, anatomically perfect, usable structures and in nanoelectronics the sizes of the devices is reducing following the Moore’s law (Fig. 2). The nano biotechnology field is so exciting because it converges the angstrom, nano and micro scale worlds with the exploitation of physical principles, chemical synthesis capabilities and functional properties of biological nanostructures. Nature has made highly precise and functional nanostructures: DNA, proteins, membranes, filaments and cellular components. These biological nanostructures typically consist of simple molecular building blocks of limited chemical diversity arranged into vast numbers of complex three dimensional architectures and dynamic interaction patterns.

Physical properties of nanoparticles

Some known physical properties of nanomaterials are related to different origins: for example, (1) large fraction of surface atoms, (2) large surface energy, (3) spatial confinement, and (4) reduced imperfections. Some of there physical properties are:

1. Nanomaterials may have a significantly lower melting point or phase transition temperature and appreciably reduced lattice constants. This is due to a huge fraction of surface atoms out of total number of atoms. The enhancement in the mechanical strength (by one or two orders of magnitude) is simply due to the reduced probability of defects.

2. Optical properties of nanomaterials are significantly different from bulk crystals. For example, the optical absorption peak of a semiconductor nanoparticle shifts to a short wavelength, due to an increased band gap. The color of metallic nanoparticles may change with their sizes due to surface plasmon resonance. Electrical conductivity decreases with a reduced dimension due to increased surface scattering, while electrical conductivity of nanomaterial could be enhanced appreciably, due to the better ordering of microstructure.

3. Ferromagnetism of bulk materials disappears and transfers to super magnetism in the nanometer scale due to the huge surface energy. Self-purification is an intrinsic thermodynamic property of nanostructures and nanomaterials. Any heat treatment increases the diffusion of impurities, intrinsic structural defects and dislocations, and these can be transferred to the surface.

4. At the nanoscale, inertia and gravity would make no difference. The bacterium swimming through the water comes to a stop in a distance less than the diameter of the hydrogen atom. Attractive forces, such as van der Waals forces, and viscous
forces between small objects are much stronger than the forces of gravity and inertia at that scale. As a result, all of these molecules and machines and cell parts are in constant motion, being pushed and pulled around in quick, random trajectories.

5. Nanoelectronic devices have the advantage of having higher integrating densities and also exhibit interesting properties in the radiofrequency region, thereby offering challenges and opportunities alike.

Methods in nanoparticles fabrication

There are two methods involved in nanomaterial synthesis and fabrication of nanostructures (1) top down, and (2) bottom up approach.

Top down approach—Attrition or milling is a typical top-down method in making nanoparticles, whereas the colloidal dispersion is a good example of bottom up approach in the synthesis approach, since the growth of thin films is bottom up whereas etching is top down, while nanolithography and nano-manipulation are commonly a bottom up approach. Both these approaches play an important role in modern industry and most likely in nanotechnology as well. However there are advantages and disadvantages in both type of approach.

Biggest problem with top down approach is the imperfection of the surface structure. It is estimated that conventional top-down technique such as lithography can cause significant crystallographic damage to the processed patterns, and additional defects may be introduced even during the etching defects. For example, a nanowire made by lithography is not smooth and may contain a lot of impurities and structural defects on surface. Such imperfections would have a significant impact on physical properties and surface chemistry of nanostructures and nanomaterials, since the surface over volume ratio in nanostructures and nanomaterials is very large. The surface imperfections would result in a reduced conductivity due to inelastic surface scattering, which in turn would lead to the generation of excessive heat and thus impose extra challenges to the device design and fabrication. Despite the limitations in the process the method is widely used for its simplicity and relative ease.

However the problem with top down approach is that the particles it produces have fairly broad size distribution, and varied particle shape. In addition they may contain a significant amount of impurities from the milling medium and the defects therein. Such prepared nanoparticles are commonly used in the preparation of the nanocomposites and nanograin bulk materials, which require much lower sintering temperatures. In nanocomposites and nanograin bulk materials, defects may be annealed during sintering; size distribution, particle shape, and a small amount of impurities are relatively insensitive for their applications.

Repeated thermal cycling may also break a bulk material into small pieces, if the material has a very small thermal conductivity but a large volume change as a function of temperature. A big volume change associated with phase transition can be effectively utilized in this approach. Although very fine particles can be produced, this process is difficult to design and control so as to produce desired particle size and shape. It is also limited to materials with very poor thermal conductivity but a large volume change. Lithography is another method to produce small particles.

Bottom up approach—Bottom up approach is to build material from bottom: atom by atom, molecule by molecule, or cluster by cluster. Bottom up approach is used in the fabrication and processing of nanostructures and nanomaterials on a very large scale, and has been in laboratory use and in industry. Examples are use of sodium and nitrate in industry.

Bottom up approach offers a better chance to obtain nanostructures with less defects, more homogenous chemical composition, and better short
and long range ordering. This is because the bottom up approach is driven mainly by the reduction of Gibbs free energy, such that nanostructures and nanomaterials produced are close to thermodynamic equilibrium. On the contrary, top down approach most likely introduces internal stress, in addition to surface defects and contaminations.

Bottom up approaches are far more popular in synthesis of nanoparticles and are synthesized by homogenous nucleation from liquid or vapor or by heterogenous nucleation on substances. Nanoparticles or quantum dots can also be prepared by phase segregation through annealing appropriately designed solid materials at elevated temperatures. Nanoparticles can also be synthesized by confining chemical reactions, nucleation and growth processes in a small space such as micelles. Various synthesis methods or technique can be grouped into two categories: thermodynamic equilibrium approach and kinetic approach. In the thermodynamic approach, synthesis process consists of (1) generation of supersaturation, (2) nucleation, and (3) and subsequent growth. In the kinetic approach, formation of nanoparticles is achieved by either limiting the amount of precursors available for the growth such as used in molecular beam epitaxy, or confining the process in a limited space such as aerosol synthesis or micelle synthesis.

Nanoparticles discussed here are single crystal, polycrystalline and amorphous particles with all possible morphologies, such as spheres, cubes and platlets. In general, the characteristic dimension of the particles is not larger than several hundred nanometers. If the nanoparticles are single crystalline, they are often referred to as nanocrystals. When the characteristic dimension of the nanoparticles is sufficiently small and quantum effects are observed, quantum dots are the common term used to describe such nanoparticles.

For the formation of nanoparticles by homogenous nucleation, a super saturation of growth species need to be created. An obvious suggestion would be to lower the temperature of an equilibrium mixture, such as \( \text{CdS} \) and \( \text{ZnSe} \). One method is to generate a supersaturation through \textit{in situ} chemical reactions is by providing it an appropriate chemical cover.

**Semiconductor quantum dots**

The physical picturisation of a quantum dot can be done as below. If we have a box, its volume can be molecules for targeted delivery. QD’s provide sufficient surface area to attach therapeutic agents for simulating drug delivery and \textit{in vivo} imaging as well as for tissue engineering. QD-apatamer (Apt)-doxorubicin (Dox) conjugates for target cancer therapy, imaging and sensing. By varying the size and composition of quantum dots, the emission wavelength can be just about any color, from blue up through the infrared. For example, Cds and ZnSe dot can be sized to emit visible spectrum; and InP and InAs dot can emit in the far-red and near infrared. This makes possible monitoring in nanomedicine.

For the fabrication of nanoparticles, a small size is not the only requirement. For any practical application, the processing condition need to be controlled in such a way that resulting nanoparticles have the following characteristics: (1) identical size of all the particles (uniform size distribution), (2) identical shape or morphology, (3) identical chemical composition and crystal structure that are desired among different particles and within individual particles, such as core and surface composition must be same, and (4) individually dispersed or non-dispersed, i.e. no agglomeration. If agglomeration does occur, nanoparticles should be readily re-dispersible.

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**Nanoparticles through homogenous nucleation**

For the formation of nanoparticles by homogenous nucleation, a super saturation of growth species need to be created. An obvious suggestion would be to lower the temperature of an equilibrium mixture, such as saturated saturation would lead to supersaturation. One method is to generate a supersaturation through \textit{in situ} chemical reactions is by providing it an appropriate chemical cover.

**Quantum dot and quantum structures**

The physical picturisation of a quantum dot can be done as below. If we have a box, its volume can be
reduced, if we can shorten its length, its width or its height. When all three dimensions are minimized, we are left with a dimensional less parameter called “quantum dot”. The dot can be a particle located inside a larger structure or on its surface. Because quantum wells and quantum wires each have at least one dimension in which the electrons are free to move, these structures are said to exhibit “partial confinement”. Quantum dots exhibit “total confinement”. With quantum dots, the number of electrons per unit volume remains level until the next higher allowed energy state at which point the number jumps up.

When a material is reduced to a low number of atoms, the energy band spreads out and breaks into discrete levels, the band gap widens. Semiconductor particles at the size scale where this is possible are known as quantum dots. The smaller the size of quantum dot the larger is the band gap. This enables us to adjust the boundaries of the band gap simply by adding or removing material, thereby changing the energy of the photon it absorbs. This then clarifies the reason for the shift in the optical absorption and emission of quantum dots toward shorter wavelengths (blue shift).

Colored quantum dots with varying absorption/emission characteristics can be used in tagging and tracking biological species, in anticoagulating applications to create special dyes and in chemical sensing. For example CdSe can be made to seep into tumors in the body. Then, when exposed to light, the particles glow-helping surgeons to zero on sick cells and leave out the healthy ones.

The quantum dot is unique because the density of states function ceases to be continuous. There are specific numbers of states for the electrons to occupy at a given energy, and there are no more states available until the next energy. Consequently, the number of free electrons in a given volume stays constant between one allowed energy and next. The more we confine the dimensions, the more the density of states functions looks like that of an atom. When we constrain electrons inside a region of minimal width, we create a “quantum well”. Constraining the depth of the electron’s domain, leads to the creation of a “quantum wire”. We change their size and their band gap changes (Fig. 3).

Silicon nanocrystals are in great demand because of their utility as an electronic material, but is an indirect band gap material which makes it poor light material. On the other hand III-V semi-conductor is direct band gap material and thus preferred for photonic applications. QD also found application in the near infrared (NIR) imaging (700-1000 nm). Thus QDs have tremendous potential in vivo imaging and have been accordingly used, lymphatic mapping in animal model.

**Carbon nanotubes**

Working with carbon nanotube is a matter one of its alignment. Strength of carbon nanotubes stems from the fact that aligned tubes are stronger along their length (Fig. 4). Carbon nanotubes hold great promise in the making of materials with superior mechanical, electrical, and thermal properties. Strength has been the major benefit of carbon nanotube fibers, but along with this the light weight conductive wires would greatly impact energy distribution. Finding a light weight, durable, energy efficient alternative to traditional wires not only would help space endeavors, but also could boost the creation of more fuel-efficient cars and other everyday items.

Carbon nanotubes and fullerenes are shown to exhibit unusual photochemical, electronic, thermal and mechanical properties. It is also shown that single-walled carbon nanotubes (SWCNTs) could behave metallic, semi-metallic, or semi-conductive one-dimensional objects. Very high tensile strength

![Fig. 3—Three quantum structures and their electronic properties. The dimensions of a bulk material (a) can be reduced in three dimensions to confine electron motion. By constraining width a "quantum well" (b) is created, and by also constraining depth, a "quantum wire" (c) is created When all three dimensions are minimized, a "quantum dot" (d) is formed, having electronic properties much like that of an atom.](image)

![Fig. 4—A schematic representation of carbon nanotube](image)
(~100 times that of steel) of ropes made of SWCNTs has been determined experimentally\(^3\). When dispersed in another medium, it is demonstrated that SWCNTs could retain their intrinsic mechanical attributes or even augment the structural properties of medium host. SWCNTs have similar electrical conductivity as copper and similar thermal conductivity as diamond.

**Nanophotonics**

The optical properties do not depend entirely on the material; they also depend upon the size of the material. In particular, the size of an aluminium particle changes the wavelength of light that it will absorb and scatter. This is thus suggestive that the particle size can be manipulated to have the absorption in the visible region and in general which color the particle will be absorbing. As it turns out silver and gold will turn color in this way. When the particles are made smaller and smaller, the mean free path of the electrons gets shortened, leading to more surface interactions. This changes the photonic behavior. We change the particle colors. The gold particles in the range of 6 to 20 nm in diameter, absorbs the shorter wavelengths of blue and yellow light and not the longer wavelengths (red), which when passed through window, make it appear red. Above diameter of 20-25 nanometer, the absorption peak broadens and shifts to longer wavelengths. The gold color changes from ruby red to purple, then violet, and finally pale blue for particles about 160 nm in diameter. Above this size, the particles become gold in color again\(^4\). If we take a gleaming, yellow brick of gold and make it very thin, it turns blue or if we take nanometer scale particles from the same block of gold, they can be orange, or purple, or red. Nanophotonics are the nanoscale interaction of photons and materials. Nanophotonics is helping to rewrite the rules governing what can be done with photons. For example, near field microscope can be used to see things smaller than the wavelength of light.

Sun is the ultimate source of energy. However solar cells used to capture these photons have low efficiency, not exceeding 40%. A typical band gap in solar cell is 1.4 eV and hence the energy exceeding this is absorbed, while photons having energy less than this are scattered or pass through the cell. The photon energy in this region is wasted. A method to improve efficiency is to use solar cells having multiple band gaps. This may be possible with using multiple materials. The high band gap material can absorb the high energy photons with minimal heat loss, while the low band gap material soaks up the remaining low energy photons. This phenomenon is called impact ionization and may be quantum dots be used to fix energy from the sun. However, the crystals with this structure are difficult to fabricate. A schematic representation of the nanophotonic applications is shown in Fig. 5.

Light emitting nanocrystals could potentially act as luminescent converters and in addition the oxide coated nanocrystal could also act accordingly because

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**Fig. 5**—Nanophotonics in fixation of polar energy.
of the presence of sub band gap interface states, thereby increasing the efficiency of crystalline solar cells.

**Biomedical applications**

It is now well established that epigenetic changes in DNA are one of the primary causes of cancer. Currently the practice is on to mix quantum dots to bind and detect DNA through bioin. Methylated DNA is quantified using Fluorescence Resonance Energy Transfer and quenching measurements monitored by confocal microscopy gives indication of hyper methylation.

Metal particles can be coated with specific type of molecule that is known to bind another specific target molecule. When these “functionalized” particles are introduced to an environment to probe if the target molecules may be present, we can monitor color changes or just keep track of where color particles end up in order to detect identify, and all sorts of molecules. In particular if gold particles are chemically coated with a snippet of DNA, and then add the particles to a solution containing an unknown strand of DNA, the solution will turn from red to blue if the sequence match and the dots aggregate. Otherwise, the solution remains red. Detecting specific DNA sequences is critical to diagnosing genetic and pathogenic diseases.

A study carried out by Prakash and Behari to study the process of controlling osteoporosis with the injection of nanoparticles in the rat model.

The study aimed to use hydroxyapatite nanoparticles (HAP) as a countermeasure to prevent osteoporosis induced by simulated microgravity Fig. 6. Hind-limb suspension (HLS) was used in rat model to simulate microgravity induced bone losses for 45 days. In order to compare the resulting changes, mineralogical (bone mineral density [BMD], calcium [Ca], and phosphorus [P]), biochemical (osteocalcin, alkaline phosphatase [ALP], and type I collagen), and histological (scanning electron microscopy) parameters were measured. As a support to the above and to assist HAP in precipitation in the void, pulsed electromagnetic field (PEMF) was also synergistically applied. Three-month-old female Wistar rats were randomly divided into control, HLS, HLS with PEMF, HLS with HAP nanoparticles, and HLS with HAP and PEMF groups. Following observations were made (1) significant decrease in BMD, Ca, P, type I collagen, and ALP activity in femur and tibia in hind-limb bone and serum osteocalcin in HLS rats as compared with the ground control; (2) nonsignificant increase in BMD Ca, P, type I collagen, and ALP activity in femur and tibia in hind-limb bone and serum osteocalcin in HLS + PEMF rats compared to HLS + Hap as rats compared to HLS rats; (4) significant increase in BMD, Ca, P, type I collagen, and ALP activity in femur and tibia in hind-limb bone and serum osteocalcin were also observed (HLS + HAP Vs HLS + HAP + PEMF) (Fig. 7A and B). Results suggest that a combination of low level PEMF and Hap nanoparticles has potential to control bone loss induced by simulated microgravity.

**Electromagnetic heating**

Electromagnetic fields interact with tissues in two ways: oscillation of free electrons and ions and rotation of polar molecules according to the excitation frequency.

The internal electric field, which is parallel to the skin surface, is responsible for energy transfer into biological structures. Microwave tissue attenuation depends on the tissue water content and on the frequency. For homogenous tissues and plane waves, attenuation as a function of depth is quite exponential.

For deep-seated tumors, two methods have recently been proposed: one is the use of interstitial antenna and the other is that of RF needle electrodes. However, in the passage of these through the intervening tissue medium may cause infection. An alternative technique to circumvent this problem is the use of ferromagnetic seeds. Technique also has the disadvantage of desirability to remove these (once implanted) by operating for the second time.

Still another alternative to treat this problem is by use of nanoparticles (ferromagnetic particles) inserted at the desired site encapsulated within a porous
biodegradable tube. By appropriate selection of the operating frequency (2 MHz), most of the energy will be preferentially deposited in the ferromagnetic particles. The tumor tissue is heated via the conduction process from the heated ferromagnetic particles. The advantage of this method is that it can be extended over a period of time depending upon the demand of the situation and the particles will be excreted in due course. Here an accurate implantation of particles may not be required, while a distribution over the tumor volume is needed. The heating coil can be targeted over the affected volume. This method has however yet to find a broad clinical acceptance.

**Biological shapes at the nanoscale: Carbon and water are the essential tools**

Presence of water ensures that everything is wet but also accounts biomolecular machines to interact with each other. Almost all the molecules in a cell contain carbon except water. Water is a polar molecule, and electrically charged and as such other polar molecules, e.g. alcohols, sugars, and molecules with oxygen-rich regions, are all attracted to water’s Polar Regions. However, the carbon rich area of a molecule tends to be hydrophobic and will not easily form hydrogen bonds with water. Molecules containing carbon-rich areas, therefore pull these areas inwards, thus causing biological molecular machines to fold into their unique shapes that endow such molecules with very specific chemical functionalities. The forms assumed by DNA, RNA, and most proteins are such that hydrophilic regions are on the outside. In contact with water, hydrophobic regions bunch into the core.

**DNA nanotechnology**

Because of the information contained and programmability Watson-Crick base pairing of DNA molecule has been proposed as a template. This may be for the design of a one dimensional nanostructures with the purpose of generating electronic devices and biological manipulation.

1. The formation of three dimensional structures are built from DNA building blocks.
2. The rapid, single-molecule analysis of nucleic acids using nanopores. In this approach, single stranded DNA or RNA is translocated through a voltage biased nanopore in a linear manner, thereby blocking the open pore ionic current. A prerequisite for this method to work is that the diameter of the nanopore must accommodate the single stranded DNA or RNA only.
3. The enormous sequence of Watson-Crick base pairing together with the possibility to synthesize any DNA sequence can lead to artificial DNA structures. Also the short fragments provide great

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Fig. 7—SEM image of cortical part of femur (A) control, (B) hind-limb suspension, (C) hind-limb suspension + PEMF, (D) hind-limb suspension + PEMF + nanoparticle.
Nanoparticles for biological assays—Nano-particles have found widespread use for biological assays. These纳米材料 have substantial advantages over classical organic dyes because of their superior photo physical properties, which overcome many of the spectral limitations as molecular fluorophones. Semiconductor quantum dots, for example, have tunable, narrow emission spectra with very high photostability. They have the advantage of a single exciting wavelength providing for multiple emission wavelengths. Quantum dots also appear to be valuable reagents for nucleic acid bioassays including single nucleotide polymorphism analysis. Noble metals such as colloidal gold (1-5 nm in diameter) are popular staining agents in biological electron microscopy, appearing dark in transmission electron microscope images (due to high Au density) and bright in scanning electron microscopy images (due to high backscatter coefficient).

In addition, colloidal gold has been successfully used for biological assays such as DNA hybridization. Super magnetic nanoparticles such as iron oxide particles (Fe₃O₄) have enormous potential, for separation and biomolecular assay applications. They can be magnetized in a magnetic field, but than re-dispersed after removal of the field.

Nanoparticles in drug delivery—New type of drug delivery vehicles are in high demand. Top-down melling processes can be used to reformulate highly insoluble drugs as nanoparticles, thereby providing more efficient uptake. Liposomes inside pharmaceutical encapsulated have also been in use. Although liposomes exhibit outstanding biocompatibility and low toxicity, problems such as uncontrolled drug leakage and low delivery efficiency remains major obstacles.

Magnetically guided drug targeting makes use of microparticles composed of elemental iron particles and activated carbon with drug absorbance and release properties in order to direct the drug agents directly to the target tissue.

Another class of important nanoparticles is dendrimers. These are spherical nanoscale, polymeric, polyvalent molecules of well defined chemical structure. These are now being used for early treatment of cancer.

Cyclodextrins, liposome and monoclonal antibody—While physical scientists have been trying with the idea of experimenting with structures like nanotubes and buckyballs and diamondoids, in the area of biology there are other nanostructures like cyclodextrins⁹, liposomes¹⁰ and monoclonal antibodies¹¹. These nanostructures of biological origin have many applications including drug delivery and drug for deliverance.

Cyclodextrins, are cyclic Oligosaccharides. Their shape is like a truncated cone and they have a relatively hydrophobic interior. They have the ability to form inclusion complexes with a wide range of substrates in aqueous solutions. This property is responsible for encapsulation of drugs in drug delivery.

Liposome is a spherical synthetic lipid bilayer vesicle, created in the laboratory by dispersion of a phospholipid in aqueous salt solutions. Liposome is quite similar to micelle with an internal aqueous compartment. Liposomes, which are nanoscale size range, self-assemble based on hydrophilic and hydrophobic properties and they encapsulate materials inside. Liposome vesicles can be used as carriers for a great variety of particles, such as small drug molecules, proteins, nucleotides and even plasmids to tissues and into cells. For example, a commercially available anticancer drug is a liposome, loaded with doxorubicin, and is approximately 100 nanometer in diameter.

A monoclonal antibody protein molecule consists of four protein chain, two heavies and two lights, which are folded to form a Y shaped structure. It is about ten nanometers in diameter. This size (small) is important, to ensure that intravenously administered particles can penetrate small capillaries and reach cells in tissues where they are needed for treatment. Nanostructures smaller than 20 nm can transit out of blood vessels lead to increased pulmonary toxicity due to oxidative stress.

Environmental applications
Waste water treatment—In the area of water purification, nanotechnology offers the possibility of an efficient removal of pollutants and germs. Nanomaterials are now available in the form activated materials like carbon or alumina. These particles need to be incorporated into the filtration media. These are found to be very effective, though cost is a major concern. Four classes of nanomaterials that are already evaluated for water purification are:

(i) Metal containing nanoparticles (silver)
(ii) Dendrimers
(iii) Zeolites
(iv) Carbonaceous nanomaterials

The nanoparticles have unique absorption characteristics due to varying characteristics of reactive surface sites and disordered surface regions. One of the nanoparticles in recent use is magnesium oxide (MgO) and silver. These nanoparticles are very effective against Gram positive and Gram negative bacteria.

Today nanoparticles, nanomembrane and nanopowder used for detection and removal of chemical and biological substances include metals (e.g. cadmium, copper, lead, mercury, nickel, zinc), nutrients (e.g. phosphate, ammonia, nitrate and nitrite), cyanide, organics, algae (e.g. cyanobacterial toxins) viruses, bacteria, parasites and antibiotics. Basically four classes of nanoscale materials that are being evaluated as functional materials for water purification e.g. metal-containing nanoparticles, carbonaceous nanomaterials, zeolites and dendrimers. Carbon nanotubes and nanofibers also show some positive result. Nanomaterials reveal good result than other techniques used in water treatment because of its high surface area (surface/volume ratio). It is suggested that these may be used in future at large scale water purification.

It is also found that the coliform bacteria treated with ultrasonic irradiation for short time period before Ag nanoparticle treatment at low concentration, enhanced antibacterial effect. Then in future, combination of both may be the best option for treatment of waste water.

Silver nanoparticles are known to be good antibiotic agents. In a study, silver (Ag) nanoparticles (~6 nm) were synthesized using electro-exploding wire (EEW) technique. Antibacterial action of Ag nanoparticles was studied both in liquid and solid phase using colony forming unit (CFU) detection. Time and dose-dependent study of Ag nanoparticles shows that the effectiveness of particles increases with increasing particle dose and treatment time. This effect was dose-dependent and more pronounced against Gram-negative bacteria compared to Gram-

![Fig. 8—TEM images of E. coli cells](image)
positive bacteria. Transmission electron microscopy result shows particle binding with bacterial cell membrane (Fig. 8). Membrane potential assay and cytoplasm diffusion assay show the effectiveness of Ag nanoparticle used in this study. It is also found that the coliform bacteria treated with ultrasonic irradiation for short time period before Ag nanoparticle treatment at low concentration, enhanced antibacterial effect. In future, combination of both may be the best option for treatment of waste water.

A schematic presentation of nanoparticle application as presently applicable is shown in Fig. 9.

Nanoparticles and toxicity

Though there has been a rapid progress in the use of nanoparticles for a variety of purposes, their toxicological fallout is not yet explored. It was reported that titanium oxide/zinc oxide nanoparticles used in sunscreen can catalyze oxidative damage to DNA in vitro and in cultured human fibroblasts. It has been suggested that the probable dermal toxicity and morphological changes seen were due to accelerated oxidative stress in the skin after having been exposed to the single walled carbon nanotubes. In a separate study it has been demonstrated that exposure to unrefined single-walled carbon nanotube may lead to increased pulmonary toxicity due to oxidative stress. Other toxicity studies of carbon nanotube describe the cause granulomas in rats and mice after exposure. Crystalline silver nanoparticle related cytotoxicity in lesioned skin, growing human fibroblast, and keratinocytes has also been demonstrated. Nanoscale materials are now used in electronic optoelectronic, catalytics pharmaceutical, biomedical, personal care, energy and material applications.

Under some conditions QDs can become cytotoxic. It was discovered that that Cd Se particles may leak cytotoxic cadmium ions after long term exposure to UV light, while CdTe particles produce reactive oxygen species due to the loss of their protective coating after long term circulation.

While admitting that nanotechnology is the best known technique for waste water treatment, the eventual fate of the nanoparticles excreted into the water (environment) is uncertain. For the fabrication and processing of nanomaterials and nanostructures the following challenges have to be met:

1. Overcome the huge surface energy, a result of enormous surface area or large s surface to volume ratio.
2. Ensure all nanomaterials with desired size, uniform size distribution, morphology, crystallinity, chemical composition, and microstructure that altogether result in desired physical properties.

Prevent nanomaterials and nanostructures from coarsening through either Ostwald ripening or agglomeration as time evolves.

References