REVIEW

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NANOTECHNOLOGY: A COMPREHENSIVE REVIEW

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Abstract

The study of molecular and nanoscale processes is known as nanotechnology. When integrated to create bigger structures for human use, the physical and chemical characteristics of molecule size structures are the subject of nanotechnology.The control of matter at the atomic and molecular size, typically 100nm or less, is the focus of this developing field of applied science and technology. Nanotechnology's influence is growing, and nothing will escape its reach. Applications are numerous and innumerable. Although pharmaceutical fields have not yet been fully explored, nanotechnology has a significant influence on a number of medical disciplines, including biophysics, molecular biology, bioengineering, cardiology, cancer, ophthalmology, endocrinology, immunology, etc. For more effective pharmaceutical applications, nanotechnology offers intelligent systems, devices, and materials.Nanotechnology has an opposite side, much like a coin. There is little question that nanotechnology will be interwoven into every aspect of our life to make things simpler, quicker, and more durable.It's too soon to predict whether theadvancement of nanotechnology will be a blessing or a curse for the foreseeable future is yet too early to tell.

Keywords: Nanotechnology, Biophysics, Molecular biology, Bioengineering, Immunology.

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1. INTRODUCTION

Any innovation with practical applications at the nanoscale is referred to as nanotechnology.The creation and use of physical,atomic, molecular, and submicron sizes of chemical and biological systems, as well as the incorporation of the resultant nanostructures into more complex systems.In the early 21stcentury, nanotechnology is anticipated to have an enormous influence on our economy and society, on par with semiconductor technology, information technology, or cellular and molecular biology.Scientific and technological advancements in nanotechnology are expected to have a positive impact on a variety of fields, including energy, biotechnology, information technology, medicine, and national security. The next industrial revolution is expected to be brought about by nanotechnology.Greek word "nanos" (the prefix "nano" in nanotechnology) denotes "little old man or dwarf." Nanotechnology is nothing more than the basic understanding of how materials behave or operate at the nanoscale (i.e., at the atomic, molecular, or subatomic level) is essential for the development and application of innovative structures, devices, and systems. Nanotechnology is concerned with manipulating matter formations10^{-9} metres (100nm) in scale.[1-7]Nanotechnology employs two main strategies:Bottom-Up and Top-Down. Bottom-Up Approach: In this method, materials and gadgets are constructed from molecular building blocks that assemble chemically according to molecular recognition principles. These aim to combine smaller parts into intricate assemblies.Top-Down Approach: In this method, nano-objects are built from bigger entities without atomic-level precision. These aim to produce smaller devices by using larger ones to guide their assembly.The development of new nano-factories will be possible thanks to nanotechnology at the same cheap cost and quick pace as the production of several high-quality items. Nanotechnology is sometimes referred to as an exponential technology because of its exceptional capacity to replicate its own manufacturing methods. It is a ground-breaking, transformational, potent, and possibly extremely dangerousor advantageoustechnology.Improved energy systems, healthcare and medicines, food production and nutrition, information and communications technology, and water purification systems are a few of the major international development goals that nanotechnologies may be able to assist solve.[8]

2. HISTORY OF NANOTECHNOLOGY

We must first study about the development of nanotechnology in order to fully comprehend it and its applications in medicine. The study of all things tiny, even on an atomic size, is known as nanotechnology. Richard Feynman, a well-known physicist, had the original idea.He originally shared his ideas on being able to control individual atoms and molecules in 1959 to the American Physical Society at the California Institute of Technology. Feynman now presents two problems.The first project entailed building a nanomotor.[9]The Britannica encyclopaedia's letters needed to be smaller so they could fit on a pinhead, which was the second difficulty. In the area of nano science, this laid the groundwork for further investigation.The discovery of the nano scale is a critical milestone in the development of nanotechnology; without it, the field as we know it today could not have existed. As a result, it can be claimed that Moore's law, which was formulated by Gordon Moore, one of the founding members of Intel Corporation, in 1965, provided the foundation for bio molecular nanotechnology. According to this, during the next ten years, the number of transistors that can fit into a given space will double every 18 months.[10]A human hair's diameter is 200,000 nm; thus, you can get a sense of how tiny this scale genuinely is. According to Drexler, medicine is now unable to cure any illnesses.According to Drexler, medicine is now unable to cure any illnesses. However, it cannot, for instance, take an incision and join the two sides together in a way that the wound is healed as soon as it closes. It can only assist the body in healing itself.This comment makes it clear that nanotechnology has a potential application in medicine, but further research is necessary to guarantee that it will be entirely dependable and safe for patients. Nanotechnology may potentially aid in early and more accurate cancer diagnosis. According to Drexler, the immune system may be unable to recognise that a cancer cell is aberrant because it is unable to look at enough diverse traits to identify the cell appropriately. A nano machine with an on-board computer could examine 20 distinct properties of a cell before doing anything to it if it were injected into the body. The next advancement in medicine may be nanotechnology if this way of diagnostics is effective. [11]

3. NANOTECHNOLOGY DEVELOPMENTS[12]

- Throughout this decade, the total amount invested in nanotechnology multiplied ten times, and the number of patent applications in this area also increased.
- Over the past five years, major public sector R&D initiatives on nanotechnology have been announced in the UK, USA, Japan, EU, China, Korea, and Taiwan.
- After 2004, private sector expenditure will be higher than that of governments, according to a study by Lux Research (USA). Eighty percent of the 1500 firms who declared plans for nanotechnology R&D were start-ups.
- It is predicted that during the next 10 years, sales of goods made possible by developing nanotechnologies would increase to over US$3 trillion annually, creating between 1 and 2 million new employments.

4. NANOTECHNOLOGY'S OVERARCHING THEMES[12]

The results of this engineering may not share much in common with one another, such as fuel cells, textiles, or medication delivery systems, because nanotechnology is categorised according to the scale of the materials being generated and employed. The natural molecular convergence of all the fundamental sciences (biology, physics, and chemistry) is what connects them. The following themes connect these disparate domains at this level:

i. **Characterization techniques**, including as X-ray diffraction, electron microscopy, scanning tunnelling, and atomic force microscopy, are useful tools for researchers in a variety of fields because they allow them to analyse and visualise the nanostructures or the fundamental components of nanomaterials.

ii. **Nanoscale science** - Since materials' characteristics change unexpectedly at the nanoscale, it is essential to know how molecules behave at this scale in order to regulate and build nanostructures for all kinds of product applications.

iii. **Molecular level computations** - These technologies, including quantum mechanical calculations, molecular simulations, and statistical mechanics, are crucial for comprehending all molecular interactions and nanoscale phenomena.

iv. **Technology for fabrication and processing** - There are a variety of nanoparticles, powders, and suspensions that may be used directly in medicines, cosmetics, and paintings. The fabrication and assembly of additional nanomaterials into parts and apparatus is necessary. Sol-gel, chemical vapour deposition, hydrothermal treatment, and milling are a few more processing methods that are frequently used.

5. APPLICATIONS OF NANOTECHNOLOGY IN VARIOUS FIELD

Cryonics, medicine (diagnostics, drug delivery, tissue engineering), the environment (filtration), energy (reducing energy consumption, increasing energy production efficiency), information and communication (memory storage, novel semiconductor devices, novel optoelectronic devices, displays, quantum computers), and many other aspects of daily life are all impacted by nanotechnology. Additionally, it aids heavy industry (aerospace, catalysis, construction, automobile manufacturers), as well as consumer goods (nanofoods, home, optics, textiles, cosmetics, agriculture, and sports).[13]

1. Skin care and Nanotechnology:

The term "nanotechnology" has already astounded the globe and continues to do so by establishing itself by involving itself in a number of different sectors. Given that so many people today are unaware of this fascinating technology, the focus of this study is on the use of nanotechnology in dermatological preparation. Whether they are airborne or solid, different environmental nanoparticles come into touch with skin initially.

Therefore, in terms of dermatology, risks of nanomaterials include contact dermatitis caused by irritants or allergies as well as the potential for developing unexpected reactions to brand-new classes of irritants, allergens, haptens, cross-reactants, and particle-particle interactions that may cause disease.

2. **Photo-protection:**

Sunscreens are essential for preventing skin cancer since UV radiation and sun exposure have been related to an increased incidence of melanoma and epithelial skin cancer. Sunscreens are an essential component of anti-aging cosmetic solutions.Antioxidants, repair mechanism stimulators, and physical photon blockers are the current three photoprotective techniques. Nanoscale organic chemical substances like zinc oxide (ZnO) and titanium dioxide (TiO_2) can absorb, distribute, or reflect ultraviolet light. There is sufficient data to conclude that while nanoparticles can enter the top sections of human hair follicles or the stratum corneum, they are unable to cross the barrier of intact skin and reach the living epidermis. Quantum dot nanoparticles, which have a size comparable to sunscreen formulation particles (30nm.), increase the behaviour of TiO_2 nanoparticles after being applied topically to skin exposed to UV rays.[14-16]Other nanoparticle structures, like liposomes or solid lipid nanoparticles, have been used in sunscreen formulation as penetration enhancers that also improve stability and tolerance for the active moiety. This has raised safety concerns because it has been demonstrated that these particles can penetrate into the viable epidermis and dermis, depending on their size and surface chemistry.[17-21]

3. **Nano-diagnostic**

Due to benefits like the better sensitivity of associated detection techniques, which permit conducting analyses on tiny amounts of tissue samples, number of particles is now being evaluated in novel diagnostic applications. For instance, super paramagnetic nanoparticles, quantum dots with magnetic characteristics, and gold nanoparticles.[22-24]

4. **Nanomedicine**

One of the early uses of nanocrystalline silver in medicine was as an antibacterial agent for the treatment of wounds. A lotion using nanoparticles has been found to combat staph infections. The nitric oxide gas in the nanoparticles is known to destroy germs.According to studies done on mice, employing a cream with nanoparticles to produce nitric oxide gas at the site of staph abscesses greatly decreased the infection. antibiotic-containing nanocapsule-coated burn dressing. If an infection develops, the dangerous bacteria in the incision triggers the nanocapsules to rupture, releasing the medicines.As a result, infections may be treated considerably more quickly and dressing changes are needed less frequently. The eradication of bacterial infections in a patient in a matter of minutes as opposed to administering antibiotic therapy over the course of many weeks is a welcome concept in the early phases of investigation.When an allergic reaction occurs, free radicals are produced. Bucky balls can be utilised to capture these radicals and stop the ensuing inflammation.With the least amount of harm to the surrounding healthy cells, nanoshells may be utilised to concentrate the heat from infrared radiation to kill cancer cells. Such a therapy has been created by Nanospectra Biosciences and has been given the all-clear for a pilot study on human subjects utilising nanoshells lit by an infrared laser. X-rays can activate nanoparticles, which then produce electrons that kill cancer cells they have attached themselves to. This is designed to be used instead of radiation therapy and cause far less harm to healthy tissue.For this method, preclinical results have been made public by Nanobiotix. By absorbing water and forcing blood in a wound to clot fast, aluminium silicate nanoparticles can lessen bleeding in trauma victims more quickly. Medical gauze made by Z-Medica employs aluminosilicate nanoparticles. boost immune defence to combat respiratory infections.[11]

5. **Nanodrug Delivery**

The application of nanotechnology to medicine, particularly more specifically to the administration of drugs, is expected to grow quickly. To get the medicine into the body where it is required, avoiding potential adverse effects to healthy organs, is one of the biggest hurdles in drug delivery.This is particularly difficult when treating cancer since the tumour may spread to different organs as discrete metastases. Chemotherapeutics cannot be used to their full therapeutic potential due to their unrestricted cytotoxicity. Localised drug concentrations are raised as a result of localised drug delivery or localised drug targeting, which also offers methods for more specialised treatment. The instruments that allow these tactics are particular nanoparticles. These include advantages such as their small size, which enables them to penetrate cell membranes, the binding and stabilisation of proteins, and the escape of lysosomes following endocytosis. Since a long time ago,[25,26] researchers have been examining how chemotherapeutics can be trapped in nanosized formulations like liposomes.Additionally, the toxicity effect has also been researched because of the numerous professional reports about the toxicity of nanoparticles. The toxicological profile of the bulk substance, however, cannot be relied upon when the item is utilised in a nanoformulation. It is evident that a case-by-case risk benefit analysis and safety review must be conducted to prevent any adverse effects. [27]

6. Benefits of Nanotechnology

Since Feynman and Drexler's time, nanotechnology has advanced significantly. Consumer goods like sunscreens, shampoos, and cosmeceuticals have been created.Consumer goods like sunscreens, shampoos, and cosmeceuticals have been created. Treatments for a range of skin illnesses are being investigated in the laboratory, and diagnostic tools and technologies are still in the early phases of development.[28]

1. Consumer goods

A sunscreen is a lotion, spray, gel, or other topical substance that helps prevent sunburn by absorbing or reflecting part of the sun's ultraviolet (UV) radiation on skin that has been exposed to the sun.[29]To enable formulation in invisible and aesthetically pleasing carriers, a few businesses have created sunscreens employing nanosized titanium, zinc, and iron. Retinoids exhibit irritation and instability. Retinoids that have been nano-encapsulated are more stable, and since their release can be regulated and reduced, there is less irritability. An active component can be placed in the centre of solid lipid nanoparticles or nanostructured lipid carriers to postpone release. Perfumes, which provide all-day smell, benefit from slow-release kinetics.[30]Additionally, they help to extend the effectiveness of insect repellents like N, N-Diethyl-meta-toluamide (DEET). Stains,dirt,and microbes can be repelled by fabrics with extremely hydrophobic "nanowhiskers" (On each textile fibre, there are tiny projections that resemble hairs).The bulk of silver is inert. Even resistant germs like staphylococcus aureus are very hazardous to silver at the nanoscale.[31,32] Health care personnel can benefit from nano-silver-impregnated fabrics since they are antibacterial. To reduce the risk of wound infection, nano-silver is now being added to bandages and dressings. Nano-silver used in washing machines enables energy-efficient disinfection at lower temperatures.

2. Therapeutic agents

One of the key locations where dermatologic illness might progress is epicutaneous medication delivery. Some of the agents created by nanotechnology will be recognisable, but others will challenge and fundamentally alter our present approaches to dermatologic care. Drugs enclosed in nanoparticles or polymers will be targeted for release and action while also being stabilised.Nitric oxide, a biologically active version of trapped nanoparticulate volatile antimicrobial gases, has showed promise in the treatment of skin infections and when trying to penetrate abscesses, it works especially well.[33]Topical steroids with encapsulation, which build up in the epidermis but do not reach the dermis, are currently being developed. These substances will be useful for treating spongiotic dermatoses.They can also lessen the possibility of negative effects caused by corticosteroids. Soybean oil in bulk is not poisonous. Soybean oil nanoemulsions are used in disinfectants because they are antibacterial.Onychomycosis, or fungal infections of the nails, and acne are currently being treated using nanoemulsions of various substances that may enter the nail and the pilosebaceous unit.Small inhibitory ribonucleic acids (siRNAs) can be specifically induced to stimulate gene expression using polymeric nanoparticles.Genodermatosis, a skin disorder with hereditary roots, has been treated using nanoencapsulated siRNAslikewise for the efficient targeted delivery of a test gene expressed in melanoma and its inhibition in human trials.[34,35]When temperatures rise above a critical point, thermosensitive polymers that were used to encapsulate the drug dissolve, releasing it. These are used to deliver medications to inflammatory sitesand is being created to specifically target release wherever external heat is applied.It is possible to design topical nanoparticles to stimulate humoral and cell-mediated immunity.[36, 37]Microneedle patches have been demonstrated to gently localise vaccine administration to the epidermis and reticular dermis, where the majority of Langerhans cells and dermal dendritic cells are found, eliciting a powerful immune response.[38,39]

3. **Diagnostic tools**

One of the fascinating aspects of dermatology is the importance of the physical examination in diagnosis. Most skin diseases are visible with careful and knowledgeable monitoring.To aid with or substantiate a skin condition diagnosis, dermatologists still employ specialised equipment and testing. The instruments of the nanotechnology age will be far less intrusive than our punch biopsy and will not resemble our fabrication of potassium hydroxide slides at all. Small semiconductors are known as quantum dots.[40,41]They emit a vivid fluorescent colour after absorbing the desired light wavelengths. It is possible to connect quantum dots to markers like antibodies. Without the use of radioactivity, fluorescent quantum dots have been used in animal models to create sentinel lymph nodes and to visualise skin tumours.[42]A nanopunch is a tiny, basic biopsy instrument made of layers of copper, nickel, silicon, and chromium arranged like the clawof an origami bird.The claw may shut and open like a Venus flytrap as the temperature changes because the layers' different coefficients of expansion. A magnetic field can govern the movement of the nanopunch since it is paramagnetic. The liver, fascia, and difficult biopsy sites like the nail matrix may all be reached by injecting it into the circulation.Temperature control and magnetic trapping might be used to remove the claw from a urine sample. Once released for analysis, tissue might be used. To the contrary of their bulk precursors, carbon nanotubes conduct electricity. macromolecules like nucleic acids and antibodies are examples of those to which it can be linked. The conductivity of a carbon nanotube is different when coupled molecules are present than when the material is in its unmodified condition. If the linked molecules bind to the appropriate receptors, conductivity is further changed. Additionally, a sub-organellar biomarker sensor with high sensitivity can be created using the conductivity of the material.Skin infections and maybe cancers can be accurately diagnosed in real time using single biomarkers or tandem arrays. Sensors made of carbon nanotubes could be able to find minuscule amounts of substrate.[11]

7. **Negative aspects of nanotechnology[8]**

Although the world is provided with many opportunities and advancements thanks to nanotechnology, there are some serious debates about how prevalent it is globally. The improvements achieved in different fields since the advent of nanotechnology are well known to a large portion of the global population. Yet they are largely unaware of the potential risks and covert dangers associated with nanotechnology. There are benefits and drawbacks to most technology. Additionally, nanotechnology has some negative effects, particularly on humans. Cytotoxicity is by far the most problematic aspect of nanoparticles. When the particles are polluted with hazardous or damaging substances, cytotoxicity might result.With the mass production of nanoparticles, the likelihood of such contamination rises. Therefore, nanoparticles have the opposite effects on the body than what is beneficial. The expense of employing nanotechnology is quite high because the finished product is entirely composed of molecules. Even while such pricey things could be able to provide patients with a long-lasting cure, they are exceedingly tough to make. Additionally, maintenance is expensive. The original product might not be salvageable due to the harm caused by the nanotechnology product; hence it will be discarded. The single factor that can cause a nano-emulsion to become unstable is Ostwald ripening.

The erratic nature ofNano-emulsion is caused by a number of key phenomena, including creaming flocculation, coalescence, and Ostwald ripening. Since the nano-emulsion is small and uses a non-ionic type of surfactant, Ostwald ripening is the primary mechanism of nano-emulsion instability. In Ostwald, small droplets with a high radius of curvature grew to be large droplets with a low radius of curvature. One big droplet form when two smaller ones disperse. As a result, after extensive storage, the distribution of droplet sizes moved to big sizes, and the nano-emulsion's transparency darkened. Ostwald ripening has also shown to cause issues with formulation delivery.The proof of Ostwald ripening has been supported by a number of ideas. The quicker diffusion rate of tiny droplets prevents creaming of nano-emulsion. The emulsion flocculates as a result of the attraction of droplets caused by the Vander wall force. Non-ionic surfactants used in nano-emulsions, however, do not provide any sort of attraction force and do not cause flocculation.Nano-emulsion's droplet size also minimises flocculation because small droplets have high curvature and Laplace pressure prevents big droplets from deforming.[11]

Three general categories may be used to categorise potential dangers associated with nanotechnology:

A. The danger presented by sophisticated nanotechnology (or molecular manufacturing);
B. The risk posed by nanoparticles and nanomaterials to human health and the environment;
C. Social dangers.

1. **Pitfalls of nanoparticles**

The sheer existence of nanomaterials (materials containing nanoparticles) does not pose a danger in and of itself. They are only potentially dangerous because to a few factors, most notably their enhanced responsiveness and movement. The harmful effects of nanoparticles cannot be inferred from the material's known toxicity since they differ greatly from their larger-sized counterparts. Regarding the effects of free nanoparticles on human health and the environment, this raises serious problems.

2. **Health Concerns**

Nanoparticles can enter the body through a number of different channels. They can also be purposefully injected during medical operations (or released from implants), ingested, absorbed via the skin, or breathed. One of the key problems that need solving is how these nanoparticles interact within the host.The size, shape, and surface reactivity of nanoparticles with the tissue around them all affect how they behave. In addition to the possibility that unable to degrade or just slowly degrading nanoparticles build up in organs, there is also the possibility that these particles could interact with biological processes occurring inside the body. This is because, due to their large surface area, nanoparticles will immediately adsorb some of the macromolecules they come into contact with when exposed to tissue and bodily fluids.

3. **Environmental Problems**

Nanoparticles may harm the ecosystem, but there is not enough evidence to say for sure. Here, two things are significant:

i. When produced (or accidentally discharged during manufacturing) or as a waste by-product of production, nanoparticles in their free state can be released into the air or water and eventually build up in the soil, water, or plant life.
ii. They will eventually need to be recycled or disposed of as garbage if they are in fixed form and are a component of a produced item or product.

Engineered nanoparticles' whole life cycle, including their production, storage, transport, use, possible misuse, and disposal, must be assessed in order to determine the health risks they pose.

8. CONCLUTION

Although the discovery of nanotechnology has revolutionised both medical research and clinical practise, it is difficult to say that nanotechnology has had only positive effects on the world. Our daily lives are beginning to be impacted by nanoscience and nanotechnologies, which have the potential to be significant worldwide competitiveness drivers. It is feasible that conventional Indian industries would undergo radical change as a result of disruptive technologies developed by nanotechnology. India now conducts extensive research and has a developing SME nanotechnology sector. A few prominent Indian companies have also created extensive nanotechnology initiatives. Leading technologies for diagnostic tools, nanomaterials, quantum computing, and energy storage are being developed, demonstrating that it is internationally competitive in certain industries. Over the next five to ten years, Indian industry will depend more and more on nanotechnology solutions because our research and development in this area is already having a significant impact on the general economy. We must accept that nanotechnology will grow more expensive, sophisticated, interdisciplinary, and scattered if India is to continue to lead the world in the creation of industries based on it.The aim is to improve resource allocation and coordination within India's nanotechnology effort in order to take advantage of the prospects provided by this field. In order to catalyse the major efforts in India, it has been determined that both government and non-government activities are required. It would be necessary to consolidate and focus part of the research effort while also providing India with long-term funding for its core nanoscience research.There will be a need for long-term assistance with India's foundational nanoscience research as well as some concentration and clustering of the research effort.[8]When expenditures are taken into account, the investment is highly large and hence out of the reach of small-scale enterprises. The likelihood of loss is higher than the likelihood of profit because if a product fails or is damaged during research, development, manufacture, transportation, or delivery, there will be a significant financial loss. Therefore, it involves a lot of risk and demands careful consideration. It is quite difficult to weigh the benefits and drawbacks of nanotechnology in the middle of all of them.On the one hand, nanotechnology offers an incredible foundation for the world to grow in many important sectors, but on the other, it also presents a possible risk by increasing the potential for destroying the entire globe. Consequently, we can conclude that nanotechnology is undoubtedly a blessing, but how wisely and effectively it has been applied will determine whether it has been a blessing or a curse. [11]

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