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Review Paper

Nanotechnology in Industrial Pharmacy: Applications in Drug Delivery Systems

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ABSTRACT

Nanotechnology has emerged as a transformative field in industrial pharmacy, revolutionizing drug delivery systems through its ability to manipulate materials at the nanoscale. This paper explores the applications of nanotechnology in the design, development, and optimization of advanced drug delivery systems, highlighting its potential to enhance therapeutic efficacy, minimize side effects, and improve patient compliance. Key nanocarriers, such as liposomes, polymeric nanoparticles, solid lipid nanoparticles, and dendrimers, are discussed, with emphasis on their roles in targeted and controlled drug delivery. The integration of nanotechnology with advanced techniques like stimuli-responsive systems and nanotheranostics is also addressed, showcasing its significance in personalized medicine. Additionally, the paper examines the challenges and regulatory considerations in translating nanotechnology-based drug delivery systems from research to commercial-scale production. By providing a comprehensive overview, this study underscores the pivotal role of nanotechnology in shaping the future of industrial pharmacy and its contribution to addressing unmet medical needs.

INTRODUCTION

Nanotechnology is science of matter and material that deal with the particle size in nanometers. The word' nano' is derived from latin, which means dwarf (1nm=10-9m). Nanomedicine deals with comprehensive monitoring, control, construction, repair, defense and improve human biological system at molecular level using engineered nanostructures and nanodevices. Pharmaceutical nanotechnology embraces applications of nanoscience to pharmacy as nanomaterials, and as devices like drug delivery, diagnostic, imaging and biosensor materials. Pharmaceutical nanotechnology has provided more fine tuned

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diagnosis and focused treatment of disease at a molecular level. It helps in detecting the antigen associated with diseases such as cancer, diabetes mellitus, neuro degenerative diseases, as well as detecting the microorganisms and virus associated with infections. In pharmacy size reduction has an important application as drugs in the nanometer size range enhance performance in a variety of dosage forms [1]The recent research on bio-systems at the nano-scale and the nanotechnology has created one of the most dynamic science and technology domains at the confluence of physical sciences, molecular engineering, biology, biotechnology and medicine. This domain includes better understanding of living and thinking systems, revolutionary biotechnology processes,synthesis of new drugs and their targeted delivery, regenerative medicine, neuromorphic engineering and developing a sustainable environment. Nano bio-systems research is a priority in many countries and its relevance within nanotechnology is expected to increase in the future[2]

1.1.Definition and Scope

Definition:~Nanotechnology refers to the branch of science and engineering devoted to designing, producing, and using structures, devices, and systems by manipulating atoms and molecules at nanoscale, i.e. having one or more dimensions of the order of 100 nanometres (100 millionth of a millimetre) or less. In the natural world, there are many examples of structures with one or more nanometre dimensions, and many technologies have incidentally involved such nanostructures for many years, but only recently has it been possible to do it intentionally[3].

Scope:~ Nanotechnology in the pharmaceutical industry has a wide range of applications, including

Drug delivery: Nano-engineered tools and devices can improve the delivery of drugs to specific cells in the body, reducing the risk of failure and rejection.

Diagnosis and treatment: Nanoparticles are being used to treat various diseases, including kidney diseases, tuberculosis, skin conditions, Alzheimer's disease, and different types of cancer. **Imaging:** Nanotechnology can develop more powerful contrast agents for imaging techniques, improving resolution and specificity, and indicating the diseased site at the tissue level. **Medical devices:** Nanotechnology can improve medical devices and develop new technologies.

Research instruments: Nanotechnology can be used to develop sophisticated research instruments to improve treatments for various ailments.

Importance and Benefits

Nanotechnology in drug delivery has many benefits, including:

Targeted delivery: Nanoparticles can be designed to deliver drugs to specific tissues, such as cancer cells, with high accuracy. #Controlled release: Nanoparticles can release drugs in a controlled manner, which can reduce side effects and increase patient compliance.

Improved drug efficiency: Nanoparticles can improve drug bioavailability and uptake of low solubility drugs. #Reduced toxicity: Nanoparticles can reduce drug-related toxicity and the risk of potential toxic reactions. #Versatile administration: Nanoparticles can be administered orally, by inhalation, or intravenously.

Long shelf life: Nanoparticles are highly stable and have a long shelf life.

#Imaging: Nanoparticles can be combined with imaging agents to monitor drug distribution and tumor targeting in real time. #Personalized medicine: Nanoparticles can be used to develop personalized medicine approaches.[4] Nanotechnology has been used to treat a variety of diseases, including cancer and AIDS Improving absorption, bioavailability, and stability can be achieved by using nanotechnology in drug delivery, and therefore overcome the defects of common DDS. Nanostructured delivery carriers can protect encapsulated drugs from in vivo degradation.[5]

Fundamentals of Nanotechnology –

Nanotechnology is the science and engineering of functional systems at the molecular scale. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up making complete, high-performance products.[6] One nanometer (nm) is one billionth, or 10^{-9}, of a meter. By comparison, typical carbon–carbon bond lengths, or the spacing between these atoms in a molecule, are in the range 0.12–0.15 nm, and DNA's diameter is around 2 nm. On the other hand, the smallest cellular life forms, the bacteria of the genus Mycoplasma, are around 200 nm in length. By convention, nanotechnology is taken as the scale range 1 to 100 nm, following the definition used by the American National Nanotechnology Initiative. The lower limit is set by the size of atoms (hydrogen has the smallest atoms, which have an approximately ,25 nm kinetic diameter). The upper limit is more or less arbitrary, but is around the size below which phenomena not observed in larger structures start to become apparent and can be made use of.[7] These phenomena make nanotechnology distinct from devices that are merely miniaturized versions of an equivalent macroscopic device; such devices are on a larger scale and come under the description of microtechnology.[8] To put that scale in another context, the comparative size of a nanometer to a meter is the same as that of a marble to the size of the earth.[9] Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition.[10] In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control.[3]

Areas of physics such as nanoelectronics, nanomechanics, nanophotonics and nanoionics have evolved to provide nanotechnology's scientific foundation.

2.1.Nanoparticles

Nanoparticles are designed with specific structures that give them their desired functions. Their size, shape, surface, and internal structures are all important for their function.

Types of Nanoparticles There are several types of nanoparticles, including:

Carbon-based: Fullerenes and carbon nanotubes

Metal: Made of metal precursors with unique optoelectrical properties

Ceramics: Inorganic nonmetallic solids that can be amorphous, polycrystalline, dense, porous, or hollow Semiconductor: Have properties between metals and nonmetals with wide bandgaps

Polymeric: Organic-based, biocompatible, and biodegradable

Lipid-based: Contain lipid moieties and are used in biomedical applications

Synthesis of Nanoparticles Nanoparticles can be synthesized using two main approaches:

Top-down process: Reduces larger structures in size.Bottom-up process: Constructs nanoparticles from individual atoms or molecules[7]

Applications of Nanoparticles Nanoparticles have many applications, including:

Drug delivery Gene therapy

Tissue engineering [11]

2.2. Nanomaterials

Nanomaterials, whether naturally occurring or human-made, are defined by their size, which is measured in nanometers. To put that into perspective, a nanometer is incredibly small, equivalent to one millionth of a millimeter, or about 100,000 times smaller than the diameter of a single human hair [12]. The National Institute of Environmental Health Sciences (NIEHS) is actively working to understand any potential risks associated with exposure to these materials [13].

Nanomaterials have unique properties that make them useful in a wide range of fields, including:

Electronics: Nanotechnology is used in electronic components and devices, where quantum mechanical properties and inter- atomic interactions are important to consider.

Energy: Nanomaterials and nanotechnology are used in renewable energy generation, energy storage devices, and fuel cells. Pharmaceuticals: Nanomaterials are used in pharmaceuticals and related areas.

Neural tissue engineering: Nanomaterials are used to support cell adhesion, proliferation, and neuronal cell differentiation. Cancer diagnosis and treatment: Nanomaterials are used to target pharmacological substances for cancer diagnosis and treatment. Cosmetics: Nanomaterials are used in cosmetics, where they can brighten the skin and inhibit free radicals caused by UV exposure.

Sensors: Nanomaterials are used as sensors.

Batteries: Nanomaterials are used as components of batteries.

Optoelectronic devices: Nanomaterials are used in optoelectronic devices.[14]

1.Nanotechnology in Drug Delivery Systems

Nanotechnology is being used to develop new drug delivery systems that can improve treatment outcomes for a variety of conditions:

Nanocarriers

These drug delivery systems can improve drug bioavailability, absorption time, and solubility in the blood. They can also target specific areas in the body, such as tumors. Some examples of nanocarriers include liposomes, micelles, polymeric nanoparticles, and dendrimers.

Quantum dots

These fluorescent semiconductor nanocrystals are used in drug delivery and cellular imaging.

Nanomicelles

These nanocarriers can be loaded with chemotherapeutic drugs and targeted to cancer cells in the brain. Their small size allows them to penetrate the blood-brain barrier.

In situ diagnostic devices

These devices can be used to image internal problems and bleeding sites. In the future, they may incorporate nano-scaled sensors to detect chemicals, bacteria, viruses, and pH. [15]

Nanotechnology has the potential to improve drug delivery in many ways, but there are also some challenges to overcome:

Toxicity

Nanoparticles can be toxic, but this can be reduced by combining them with natural products. Drug resistance

Cancer cells can develop mechanisms to deactivate or pump out drugs, which can make them ineffective

2.3 application of nanotechnology

After thorough and careful analyses, a wide range of industries—in which nanotech nology is producing remarkable applications—have been studied, reviewed, and selected to be madepartofthis review. It should be notified that multiple subcategories of industrial links may be discussed under one heading to elaborate upon the wide-scale applications of nanotechnology in different industries. A graphical abstract at the beginning of this article indicates the different industries in which nanotechnology is imparting remark able implications, details of which are briefly discussed under different headings in the next session. 2.2. Nanotechnology and Computer Industry Nanotechnology has taken its origins from microengineering concepts in physics and material sciences [16]. Nanoscaling is not a new concept in the computer industry, as technologists and technicians have been working for a long time to design such modified forms of computer- based technologies that require minimum space for the most efficient work. Resultantly, the usage of nanotubes instead of silicon chips is being increasingly experimented upon in computer devices. Feynman and Drexler's work has greatly inspired computer scientists to design revolutionary nanocomputers from which wide-scale advan tages could be attained [17]. A few years ago, it was an unimaginable to consider laptops, mobiles, and other handy gadgets as thin as we have today, and it is impossible for even Molecules 2023, 28, 661 3 of 26 the commonmantothink that with the passage of time, more advanced, sophisticated, and lighter computer devices will be commonly used. Nanotechnology holds the potential to make this possible[18]. Energy-efficient, sustainable, and urbanized technologies have been emerging since the beginning of the 21st century. The improvement via nanotechnology in informa tion and communication technology (ICT) is noteworthy in terms of the improvements achieved in interconnected communities, economic competitiveness, environmental sta bility during demographic shifts, and global development [15]. The major implications of renewable technology incorporate the roles of ICT and nanotechnology as enablers of environmental sustainability. The traditional methods of product resizing, re-functioning, and enhanced computational capabilities, due to their expensiveness and complicated manufacturing traits, have slowly been replaced by nanotechnological renovations. Novel technologies such as smart sensors logic elements, nanochips, memory storage nanode vices, optoelectronics, quantum computing, and lab- on-a-chip technologies are important in this regard [19]. Both private and public spending are increasing in the field of nanocomputing. The growth of marketing and industrialization in the biotechnology and computer industries are running in parallel, and their expected growth rates for the coming years are far higher. Researchers and technologists believe that by linking the advanced field of nanotechnology and informatics and computational industries, various problems in human society such as basic need fulfillment can be easily accomplished in line with the establishment of sustain able goals by the end of this decade[14]. The fourth industrial revolution is based upon the supporting pillars derived from hyperphysical systems including artificial intelligence, machine learning, the internet of things, robots, drones, cloud computing, fast internet technologies (5G and 6G), 3D printing, and block chain technologies [20]. Most of these technologies have a set basis in computing, nanotechnology, biotech nology, material science renovations, and satellite technologies. Nanotechnology offers useful alterations in the physiochemical, mechanical, magnetic, electrical, and optical prop erties of computing materials which enable innovative and newer products [7]. Thus, nanotechnology is providing a pathway for another broad-spectrum revolution in the f ield of automotive, aerospace, renewable energy, information technology, bioinformatics, and environmental management, all of which have root origins from nanotechnological improvements in computers. Sensors involved in software and data algorithms employ nanomaterials to induce greater sensitivity and processabilities with minimal margin-to machine errors [8]. Nanomaterials provide better characteristics and robustness to sensor technologies which mean they are chemically inert, corrosion-resistant, and have greater tolerance profiles toward temperature and alkalinity [8]. Moreover, the use of semiconductor nanomaterials in the field of quantum computing has increased overall processing speeds with better accuracy and transmissibility. These technologies offer the creation of different components and communication protocols at the nano level, which is often called the internet of nano things [9]. This area is still in a continuous development and improvement phase with the potential for telecommu nication, industrial, and medical applications. This field has taken its origin from the internet of things, which is a hyperphysical world of sensors, software, and other related technologies which allow broad-scale communication via internet operating devices [15]. The applications of these technologies range from being on the simple home scale to being on the complex industrial scale. The internet of things is mainly capable of gathering and distributing large-scale data via internet-based equipment and modern gadgets. In short, the internet of nano things is applicable to software, hardware, and network connection which could be used for data manipulation, collection, and sharing across the globe [10]. Another application of nanotechnology in the computer and information industry comes in the form of artificial intelligence, machine learning, and big data platforms which havesetthebasis for thefourth industrial revolution. Vast amounts of rawdataarecollected through interconnected robotic devices, sensors, and machines which have properties of Molecules 2023, 28, 661 4 of 26 nanomaterials [19]. After wide-scale data gathering, the next step is the amalgamation of the internet of things and the internet of people to prepare a greater analysis, understanding, and utilization of the gathered information for human benefit [5]. Such data complications can be easily understood through the use of big data in the medical industry, in which epidemiological data provide benefits for disease management [4]. Yet another example is the applications in business, where sales and retail-related data help to elucidate the target markets, sales industry, and consumer behavioral inferences for greater market consumption patterns [14]. Similarly, an important dimension of nanotechnology and computer combination comes in the form of drone and robotics technology. These technologies have a rising number of applications in maintenance, inspections, transportation, deliverability, and data inspection [3]. Drones, robots, and the internet of things are being perfectly amalgamated with the industrial sector to achieve greater goals. Drones tend to be more mobile but rely more on humancontrol as compared to robots, which are less mobile but have larger po tential for self-operation [21]. However, now, more mobile drones with better autonomous profiles are being developed to help out in the domain of manufacturing industries. These devices intensify and increase the pace of automation and precision in industries along with providing the benefits of lower costs and fewer errors [24]. The integrated fields of robotics, the internet of things, and nanotechnology are often called the internet of robotics and nano things. This field of nanorobotics is increasing the flexibility and dexterity in manufacturing processes compared to traditional robotics [25]. Drones, on the contrary, help to manage tasks that are otherwise difficult or dangerous to be managed by humans, such as working from a far distance or in dangerous regions. Nanosensors help to equip drones with the qualities of improved detection and sensation more precisely than previous sensor technologies [21,27]. Moreover, the over-potential of working hours, battery, and maintenance have also been improved with the operational ization of nano-based sensors in drone technology. These drones are inclusively used for various purposes such as maintaining operations, employing safety profiling, security surveys, and mapping areas [18]. However, limitations such as high speed, legal and ethical limitations, safety concerns, and greater automobility are some of the drawbacks of aerial and robotic drone technologies [21]. Three-dimensional printing is yet another important application of the nanocom puter industry, in which an integrated modus operandi works to help in production management . Nanotechnology-based 3D printing offers the benefits of an autonomous, integrated, intelligent exchange network of information which enables wide-scale produc tion benefits. These technologies have enabled a lesser need for industrial infrastructure, minimized post-processing operations, reduced waste material generation, and reduced need for human presence for overall industrial management . Moreover, the benefits of 3D printing and similar technologies have potentially increased flexibility in terms of customized items, minimal environmental impacts, and sustainable practices with lower resource and energy consumption. The use of nano-scale and processed resins, metallic raw material, and thermoplastics along with other raw materials allow for customized properties of 3D printing technology. The application of nanotechnology in computers cannot be distinguished from other industrial applications, because everything in modern industries is controlled by a systemic network in association with a network of computers and similar technologies. Thus, the f ields of electronics, manufacturing, processing, and packaging, among several others, are interlinked with nanocomputer science. Silicon tubes have had immense applica tions that revolutionized the industrial revolution in the 20th century; now, the industrial revolution is in yet another revolutionary phase based on nanostructures[18]. Silicon tubes have been slowly replaced with nanotubes, which are allowing a great deal of improvement and efficiency in computing technology. Similarly, lab-on-a-chip technology and memory chips are being formulated at nano scales to lessen the storage space but increase the storage Molecules 2023, 28, 661 5 of 26 volume within a small, flexible, and easily workable chip in computers for their subsequent applications in multiple other industries. Hundreds of nanotechnology computer-related products have been marketed in the last 20 years of the nanotechnological revolution. Modern industries such as textiles, automotive, civil engineering, construction, solar technologies, environmental applications, medicine, transportation agriculture, and food processing, among others are largely reaping the benefits ofnano-scale computerchipsandotherdevices. Insimpleterms, everythingout there in nanoindustrial applications has something to do with computer-based applications in the nanoindustry . Thus, all the applications discussed in this review more or less originate from nanocomputers. These applications are enabling considerable improvement andpositive reports within the industrial sector. Having said that, it is hoped that computer scientists will remain engaged and will keep on collaborating with scientists in other fields to further explore the opportunities associated with nanocomputer sciences.

3.1. Types of Nanocarriers

Nanoparticles can be categorized into different types based on their composition. These include:

Carbon-based nanoparticles: Fullerenes and carbon nanotubes are examples of this type, which have unique properties due to their carbon structure.

Metal nanoparticles: These nanoparticles exhibit distinct optoelectrical properties due to their localized surface plasmon resonance (LSPR) characteristics, making them useful for various applications.[17]

Ceramic nanoparticles: These inorganic nonmetallic solids are synthesized through heat and cooling, and have properties that make them suitable for specific uses.

Semiconductor nanoparticles: With properties between those of metals and nonmetals, these nanoparticles have potential applications in fields such as electronics and energy.[22]

Polymeric nanoparticles: These organic-based nanoparticles are biocompatible and biodegradable, making them suitable for biomedical applications.

Lipid-based nanoparticles: Containing lipid moieties, these nanoparticles are used in biomedical applications, such as drug delivery and imaging.

Here's a summary of the different types of nanoparticles in bullet points:

Carbon-based nanoparticles: fullerenes and carbon nanotubes Metal nanoparticles: unique optoelectrical properties due to LSPR

Ceramic nanoparticles: inorganic nonmetallic solids synthesized through heat and cooling Semiconductor nanoparticles: properties between metals and nonmetals

Polymeric nanoparticles: biocompatible and biodegradable Lipid-based nanoparticles: used in biomedical applications[18]

3.2Advantages of Nanocarriers in Drug Delivery

Nanocarriers have many advantages over traditional drug delivery methods, including:

Improved drug delivery: Nanocarriers can protect drugs from degradation, improve their absorption, and increase their bioavailability. [23]

Targeted delivery: Nanocarriers can be designed to target specific tissues and cells, such as tumors. Reduced side effects: Nanocarriers can minimize the toxicities and side effects of drugs by reducing the dose required. Multiple administration routes: Nanocarriers can be administered orally, nasally, topically, or parenterally.

Controlled drug release: Nanocarriers can be designed to release drugs at a controlled rate. Long shelf life: Nanocarriers are highly stable and can have a long shelf life.

Large drug capacity: Nanocarriers can carry a large quantity of drugs.

Biocompatible materials: Nanocarriers can be made from biocompatible and biodegradable materials, such as polymers or solid lipids.

Nanocarriers can be made from a variety of materials, including natural polymers like gelatin and albumin, and synthetic polymers like polylactides and polyalkylcyanoacrylates.

4.Challenges Of Nano Particles

Nanotechnology faces several challenges, including:

Production Challenges: Shrinking nanofabrication facilities to the nanometer range is a significant challenge. However, it may be possible to reduce their size to table-top machines, and eventually to matchbox scale, which would require a revolution in production strategies and facility design. Societal and Ethical Concerns [17]

Nanotechnology raises several societal and ethical concerns, including:

Military Applications: Nanotechnology may widen the gap between the military and civilian populations, and indirectly contribute to terrorism.

Intellectual Property: Establishing the uniqueness of nanotechnology patents can be difficult, leading to intellectual property issues.

Employment: Nanotechnology may lead to a drop in demand for unskilled labor, while increasing demand for scientists, engineers, and technicians.

Environmental Concerns

Nanotechnology may have negative implications for the environment, including:

Use of Nanofertilizers: The use of nanofertilizers in agriculture may have unintended consequences. Health Concerns Nanotechnology has potential applications in healthcare, but it's essential to ensure the responsible use of nanoparticles, especially in children.[15]

Sustainable Development

Nanotechnology has the potential to contribute to sustainable development by: Purifying Water: Helping to purify water

Reducing CO2 Emissions: Reducing CO2 emissions

Promoting Recycling: Promoting recycling[4]

4.1Regulatory consideration

Here is a rephrased version of the text, organized into clear sections with bullet points: Regulatory Considerations for Nanotechnology

Nanotechnology is subject to various regulatory considerations, including:

Safety

Nanomaterial Risks: Nanomaterials can be harmful to the environment and human health, as they can circulate in the bloodstream, lodge in organs and tissues, and interfere with cellular function.[24]

Standardization

Lack of International Standards: There is currently no international standardization for nanotechnology, including terminology, test methods, and protocols for evaluating environmental impact.

Product Quality and Safety

FDA Regulations: For nanomedicines, the FDA considers product quality assessment and safety assessment, including whether a product is engineered to have nanoscale dimensions or properties.

Labeling and Disclosure

Ingredient Disclosure: Companies should provide information about the ingredients in their products, including dosage, potential exposure routes, and health risks.

Environmental Impact Assessment

Environmental Risk Assessment: Companies should conduct assessments to determine the potential environmental impact of their products.

Training and Handling

Employee Training: Companies should train employees on how to properly handle and dispose of nanomaterials. Codes of Conduct

Guidelines for Responsible Practice: Codes of conduct can cover topics like occupational safety, manufacturing practices, and risk identification to ensure responsible development and use of nanotechnology

Future aspect of nanotechnology.

In conclusion, it appears to me that the use of nanotech nology in the pharmaceutical field is likely to increase for some time to come, particularly in the drug delivery/formula tion area. Moreover, I would not be surprised to see drug companies going back through their records to take another look at compounds, which in the past failed due to, for exam ple, poor solubility/bioavailability or the like, to see if they can be made more efficacious using nanotechnology tech niques. Also, there has been much discussion generally about the development of combined assay/administration devices which may employ nanotechnology. Such envisaged devices would remain in the patient and, for example, in the case of a diabetic would be able to sense their blood glucose level and administer insulin accordingly. To return to my comments made in the introduction, about what nanotechnology means to each person, there will undoubtedly be further advances in relation to nucleic acid and/or antibody-based therapies, but whether or not you con sider these to relate to nanotechnology, is somewhat up to you

5.CONCLUSION

Nanotechnology: A Multidisciplinary Field

Nanotechnology is a multidisciplinary field of science that studies and manipulates matter at the molecular level, with a wide range of potential applications across various industries.

Applications in Medicine

Early Detection and Treatment: Nanotechnology can help with early detection of illnesses, targeted drug delivery, and noninvasive vaccinations.

Cancer Treatment: Nanotechnology can aid in cancer treatment and may lead to new diagnostic methods and wearable equipment. Applications in Computing

Revolutionizing Computing: Nanotechnology has the potential to revolutionize computing and quantum computing. Applications in Communications

Revolutionizing Communication Devices: Nanotechnology has the potential to revolutionize communication devices. Applications in Dentistry Preventing Dental Caries: Nanotechnology can help prevent dental caries, for example, through the use of toothpaste containing nanosized calcium carbonate to remineralize early enamel lesions.

Impact on Education and Research

Establishment of New Laboratories and Research Centers: Nanotechnology has led to the establishment of new laboratories and research centers.

Emergence of New Curriculums: Nanotechnology has also led to the emergence of new curriculums at universities, reflecting its interdisciplinary nature and potential applications.

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