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OVERVIEW OF PHYSICOCHEMICAL AND SURFACE PROPERTIES OF NANOPARTICLES FOR ENGINEERING APPLICATIONS

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Abstract: Over the past few decades, scientists and engineers have been working on mastering the intricacies linked with nanoscale particles. Now researchers have gained valuable insight on how to create tailor-made nanoparticles with physicochemical properties never envisaged before. Theseengineered nanoparticles offer far-reaching applications in medicine, cosmetology, engineering, food packaging, and bioprocessing, to achieve specific performance goals. This review focuses on the electronic, optical, magnetic, mechanical, thermal, vibrational, and surface properties of nanoparticles, their method of preparation, technique for particle size control, and engineering applications.

Keywords: Nanoparticles, Nano-Additives, Physicochemical, Nanotechnology Surface Properties

1.0 Introduction

There is a revolutionary convergence of scientists from diversified disciplines devoted to the study of a world so tiny it is undetectable to the human eye, even with the aid of an optical microscope [1]. That world is the area of nanotechnology, the territory of molecules, atoms, and nanostructures. Nanotechnology is generally considered to deal with the matter in size range less than 100 nm, and with nanomaterials produced using nanoparticles. The Royal Society [2] describesnanotechnology as the design, characterization, manufacture, and application of systems, structures, and devices by manipulating morphology and size at the nanometric scale. A nanometre (nm) is an International System of Units (S.I.) that represents a length of 10^{-9} meters, i.e., one-billionth of a meter [3]. The term "nanotechnology" has been stretched such that it has almost become interchangeable for objects that are highly promising and innovative.

Nanoparticles have a surprisingly long history. Naturally occurring nanoparticles include organic compounds (such as polysaccharides, viruses, proteins, and many more) and inorganic (aluminosilicates, natural dust, iron oxyhydroxides, and many more), which are produced by volcanic eruptions, microbial processes, weathering, and wildfires.However, how long nanoparticles have existed in nature is unknown. Still, their human use dates back to the 4th century A.D. A Roman cup called the Lycurgus Cup was made from nanosized colloidal gold particles which surprising had

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unique optical characteristics such that the container shows a different color depending on the direction of light passing through it (i.e., red when illuminated from behind and green when illuminated from the front) [4]. Another historical occurrence was recorded in the 9th century in Mesopotamia Artisan, where artisans used nanoparticles in creating metallic lusteron pot surfaces. The size of a nanoparticle ranges between 1-100 nm. The physical and chemical properties (e.g., higher specific surface area, specific magnetization, lower melting point, mechanical strength, and optical properties) of a nanoparticle differ from their bulk materials. It is noteworthy that the definition and manner in which a nanoparticle is viewed significantly depends on its specific application [1].

Nanoparticles have emerged as one of the eminent fields of scientific research in the past few decades, such that their synthesis, characterization, handling, and application have been extensively studied. Their unique and eco-friendly properties make it easy for researchers and scientists to design or fabricate or synthesize them according to their specific needs and usage. As a result, nanoparticles have high potential applications in different disciplines such as biomedical engineering, electrochemical engineering, tissue engineering, cosmetology, chemical synthesis biotechnology, and pharmaceutical technology [5]. Nanoparticles are broadly grouped into different categories based on their morphology, size, chemical, and physical compositions.These categories include carbon-based nanoparticles, lip-based nanoparticles, ceramic nanoparticles, metal nanoparticles, semiconductor nanoparticles, and polymer nanoparticles [6]. Parameters such as time, pH, temperature, pressure, and nanoparticles can be manipulated to achieve desired results. The general methods of nanoparticle synthesis, their physicochemical properties, nanotoxicology, and techniques for particle size control and stabilization, andlimitations were highlighted and discussed in this paper.

2.0 Preparation of Nanoparticles

The synthesis of nanoparticles (nanomaterials) refers to the methods of creating nanoparticles [7]. In general, there are two main approaches to the synthesizing of nanoparticles. These approaches are the top-down (breakdown) approach and the bottom-up (build-up) approach.

2.1 Top-down or Breakdown Approach

The top-down approach involves the reduction of bulk materials into smaller units. The breaking-up of larger molecules into smaller pieces is done by the application of an external force to the solid material. Examples of such external forces include the physical processes of milling, lithography, and repeated quenching [8]. The top-down approach is not suitable for preparing nanoparticles that are uniformly shaped. A significant disadvantage with this approach is the production of materials with an imperfect surface structure. Such that these imperfections have a considerable impact on the physical and surface properties of the nanoparticles formed. The breakdown approach can be subdivided into dry and wet grinding. In the dry grinding method, the solid substance is ground by employing friction, compression, or shock, which carried out by a roller mill, tumbling mill, shearing mill, a shock shearing mill, a jet mill, etc. With this method, it is challenging to obtain particle sizes with less than 3μm because of the simultaneous occurrence of condensation and pulverization of small particles [9]. Conversely, the wet grinding of a solid substance is done using a vibratory ball mill, an agitating ball mill, a centrifugal mill, a wet jet mill, a planetary ball mill, etc. This method, unlike the dry grinding method, is suitable for preventing the condensation of the formed nanoparticles and hence obtaining highly dispersed nanoparticles. Due to the nature of particles derived from the top-down approach, they are cheap and quick to manufacture, slow and unsuitable for large scale production.

2.2 Bottom-up or Build-up Approach

The build-up approach starts from the atomic level based on the nuclear transformation or the molecular condensation (i.e., with atoms or molecules or clusters) to build-up a material. For instance, nanoparticles can be nucleated and grown from ultrafine molecular distributions in liquid or vapor phases. Scientists mostly use this approach as it offers the ability to generate nanomaterials with uniform size, shape, and disposition [10]. The bottom-up approach can be grouped into a liquid phase method and a vapor phase method. The liquid phase method can then subdivided into sedimentation methods and liquid methods. These methods have been the significant methods of preparation of nanoparticles for many years. The general technique in the sedimentation method is a sol-gel process which has extensively been used in the fabrication of metal oxide nanoparticles. The process involves the transformation of metal alkoxide solution into a sol via hydrolysis, which is accompanied by poly-condensation to gel. The liquid phase methods include direct reduction, photoreduction (using ultrasonic waves, liquid plasma, and gamma rays), chemical reduction, supercritical process, solvothermal synthesis, spray pyrolysis, and spray drying. The chemical modification of metals is the most preferred method due to the ability to fine-tune the shape and size of the nanoparticles formed by changing the dispersing agent, reducing agent, temperature, and reaction time. Also, a principal advantage of this method is the fabrication of various shapes particles like hollowed nanoparticles, nanowires nanorods, nanoplates, and nanoprisms [11].

The vapor phase method can be done either by the physical vapor deposition (PVD) method, which involves the rapid cooling of the evaporated solid or liquid material obtained by thermal decomposition (e.g., arc discharge method) to yield the desired nanoparticle. In contrast, the chemical vapor deposition method (CVD) involves a chemical reaction. The CVD method is capable of producing ultrafine particles of less than 1μm. Although the vapor phase methods reduce the presence of organic impurities in the formed particles compared to the liquid phase methods, they require the use of complicated vacuums, which are highly expensive and result in low productivity [12]. Figure 1 shows the conventional preparatory methods for nanoparticles for a top-down and bottom-up approach. Although several techniques are available for the synthesis of nanoparticles, these techniques all require the use of a device or process that fulfill the following conditions:

- control of particle size, shape, size distribution, composition distribution, and crystal structure [4]
- power of aggregation [4]
- reduction of impurity occurrence in nanoparticles (improvement of the purity)
- higher mass production, scale-up and lower costs [4]
- stabilization of physical properties, structures and reactants [4]
- higher reproducibility[4]

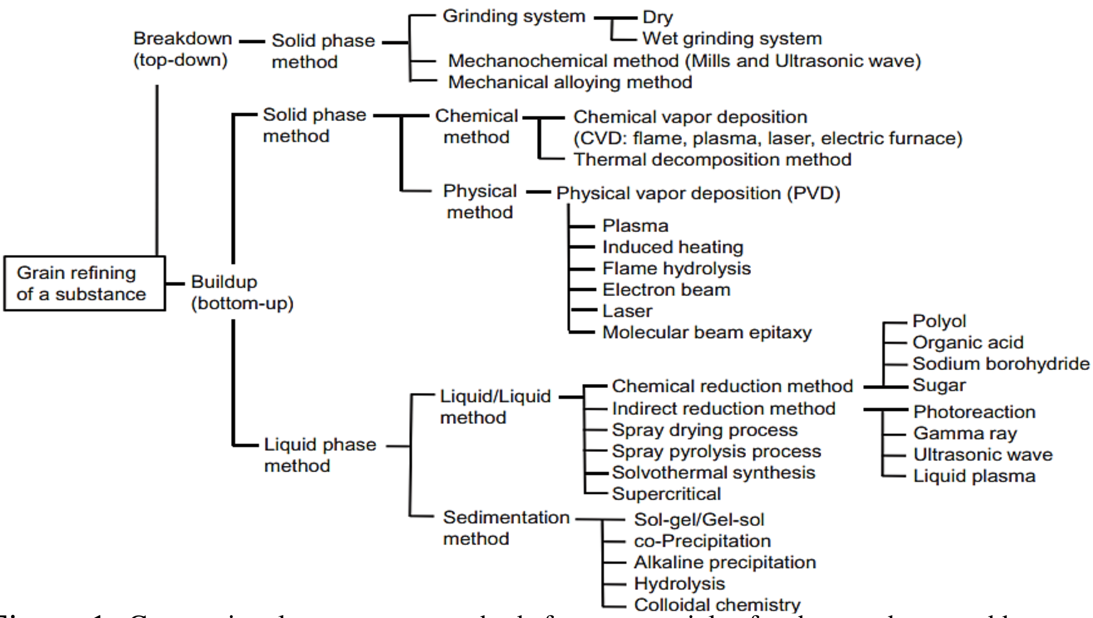

Figure 1. Conventional preparatory methods for nanoparticles for the top-down and bottom-up approach [4]

3.0 Nanoparticles with Controlled Size and Stabilisation

A key design parameter in engineering new nanoparticles is particle size control, as the physicochemical properties of nanomaterials are dependent not only on their particle size but also on their composition and shape. Particle size control is vital in imparting unique functions, identifying new utilities, and manipulating shape, purity, quality, and quantity. As a result, a high-quality synthesis protocol must be provided to control particle size and shape. Several physical and chemical methods, such as heterogeneous sol-gel[13] have been developed to improve the performance of nanomaterials exhibiting improved properties, to have better control over their particle size [14]. Controlling nanoparticle size requires an in-depth understanding of the molecular forces governing the formation of nanoparticles. Factors such as phase transition kinetics, manufacturing processes, physicochemical properties of the components, and fluid dynamics directly or indirectly influence nanoparticle size control. Flash nano-precipitation, self-assembly, and microfluidics-based preparation are a few techniques that have been developed for producing polymeric nanoparticles with the increased power of nanoparticle size between 10 to 200 nm.Figure 2 shows the structure of a nanoparticle.

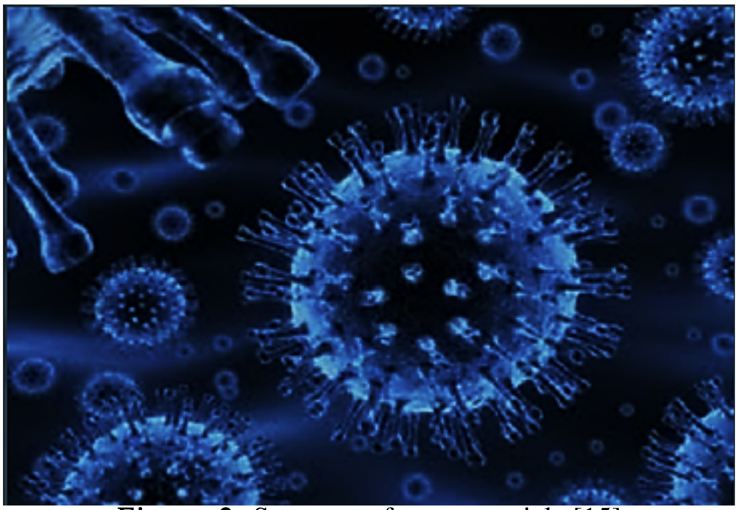

Figure 2. Structure of a nanoparticle [15]

However, the reasons why the mechanical aspects surrounding the formation of nanoparticles are not fully understood despite the availability of over 50 years of research including the published work of [16] in the role of citrate in the creation of the gold nanoparticles is not due to a lack of effort within the scientific community, but due to the high complexity of the reaction pathways.When fabricating mono-dispersed nanoparticles, it is crucial to concentrate on a single target size, especially for optical applications. The process involves a continued growth of the nanoparticles after the rapid generation of the seed particles until the desired optimum size is reached.If a decrease in particle size (i.e.,an increase in specific surface area) is observed during the growth process, a subsequent increase in surface energy occurs, which facilitates particle aggregation [9]. This occurrence necessitates the need to stabilize the surface of such nanoparticles by the addition of a dispersing agent. Examples of suitable dispersing agents capable of maintaining the high dispersivity of nanoparticles at various concentrations include gold (Au^{+}) silver (Ag^{+}), platinum (Pt^{2+}) and palladium (Pd^{2+}) which are grouped as soft acids and substrates having phosphine ($P\text{-}R_3$) and thiol (R-SH) functional groups, classified as weak bases. Also, the process temperature plays a crucial role in the fabrication of nanoparticles – higher temperatures result in better crystallization, larger agglomerates, or particles. In comparison, lower temperatures often lead to amorphous materials [17].

4.0 Physicochemical Properties of Nanoparticles

There are numerous physicochemical properties of nanoparticles, which make them remarkably unique and suitable for various applications [6]. These properties include their size, morphology, surface area, surface energy, surface roughness, mechanical strength, physiochemical stability, optical activity, chemical composition, and reactivity. In this review, the electronic. Optical, magnetic, mechanical, thermal, and surface properties of nanoparticles are discussed in the following sections [5].

4.1 Electronic Properties

Metal particles having initial bulk properties, if reduced down to a few hundreds of atoms in size, will result in a decrease in the conduction bands. The density of states, which inturn causes a considerable change in their electronic properties [13], i.e., their conductivity vanishes such that the partially continuous density of states is substituted by quantized levels with size-dependent spacing[18]. This presents an excellent opportunity for the chemistry of nanoparticles as their electronic properties are now influenceable through their particle size. Specific nanoparticles, such as the carbon nanotubes, show that their bandgap decreases with an increase in their diameter. The bandgap is the energy distance between the top filledenergy level of the valence band of electrons and the next unfilled level in the conduction band above it [18]. They are said to have high electrical conductivity with little resistance and weak transmitters of electromagnetic energy in their metallic state due to minimal defects, leaving the electrons intact.Nanotubes have been estimated to carry a billion amperes per square centimeter [19]. The electronic structure of nanoparticles can be studied using a method called U.V. photoelectron spectroscopy. More so, the electrical properties of metal nanoparticles are extensively determined by Coulomb charging energy. This phenomenon can, in principle, be understood in terms of single-electron tunneling (SET) theory [20].

4.2 Optical Properties
Nanoparticles exhibit a wide range of unusual and exciting optical properties that distinctively vary from their corresponding bulk material. This peculiar photoluminescent property causes a noticeable displacement in the optical absorption spectra towards decreasing wavelength as the particle size reduces [19]. This pronounced change is particular to the quantum dots, a subset of nanoparticles. Quantum dots are semiconducting nanoparticles with diameters less than 10nm, although the particle size may be as large as 50nm in some cases [21]. For example, noble metals nanoparticles exhibit durable U.V. By carefully controlling the size, morphology, and surface functionality of nanoparticles, a variety of optical effects can be generated to suit several useful applications. Scattering, absorption, and extinction are some of the mechanisms that influence nanoparticle optical properties. Each of these mechanisms or methods provide certain peculiar benefits depending on the target application [5].

4.3 Magnetic Properties
There has been tremendous interest in magnetic nanoparticles. This has led to them be extensively studied in recent years, and they continue to uphold interest due to their prospective application in many fields, which include biomedical applications, environmental cleanup, data storage magnetic resonance imaging. Recent literature reveals that at sizes less than the critical value, i.e., between 10-20nm, nanoparticles exhibit profound magnetic properties [22]. The complex magnetic properties displayed by magnetic nanoparticles arecontrolled by many factors such as shape, size, composition, and shell core architecture. These factors can either boost or unfavorably affect the sought-after magnetic properties. Thesemagnetic behaviors are also reliant on the method of preparation, such as thermal decomposition, solvothermal, flame spray synthesis, micro-emulsion, and co-precipitation [23].Saturation magnetization, blocking temperature, Neel, and Brownian relaxation time and coercivity are some of the critical magnetic nanoparticle parameters that can be easily influenced to achieve desired magnetic properties [24].

4.4 Mechanical Properties
The increasing demand for interface and surface properties of many mechanical systems requires new designs, manufacturing techniques, and improved surface modifications. The distinct mechanical properties of nanoparticles, such as hardness, interfacial adhesion, elastic modulus, friction, stress, strain, and movement, have allowed researchers to seek new applications in different disciplines such as surface engineering, tribology, nanofabrication, nanomanufacturing and many more [25]. Nanoparticles exhibit mechanical properties that significantly differ from the features shown by microparticles and the same bulk material, thus providing advantageous options for surface modifications of several devices in the mechanical strength or enhancedquality of nanofabrication or nano manufacturing [26]. Several applications of nanoparticles under their remarkable mechanical properties include nanomanufacturing, nanoparticle reinforced composite, coating, lubricant,and additives. Carbon nanotubes are very resilient when bent such that they do not fracture and can be straightened back without any form of impairment. This is as a result of very few structural defects and their carbon-carbon sp^2 hybridization network [19]. The Young modulus of carbon nanotubes is a measure of how flexible or stiff a material is almost ten times greater than that of steel.

4.5 Surface Properties
The interaction of nanomaterials with lipid layers and cells is critical in a wide range of applications, such as in imagining, gene delivery, and phototherapy. These applications require a rigid control over nanoparticles which are majorly governed by their surface properties, of which size and shape are a significant influence [27]. Other distinct surface properties of nanoparticles include surface charge and hydrophobicity [28].The zeta potential, also called the surface electrical potential of nanoparticles, refers to the possibility of particles under their charge in a particular environment and gives the propensity for such particles to undergo aggregation [29]. More so, the increase in absolute zero of the zeta potentials intensifies the increase in repulsion between the nanoparticles such that positively charged nanoparticles are more non-specifically internalized than their corresponding negatively or neutral counterparts. The surface of most nanoparticles are dynamics and are significantly influenced by the local environment, i.e.,Different conditions have different impacts on nanoparticles. For instance, a salty medium disintegrates the double layer and cause nanoparticle aggregation [30]. Due to this limitation, surface modification of nanoparticles becomes necessary to stabilize extreme aggregative nanoparticles in such environments. Surface modification can also be to: promote assembly of nanoparticles, functionalized nanoparticles for molecular identification, or other applications, passivate very reactive nanoparticles [31]. Many physical properties of nanoparticles, such as solubility and stability, are much dependent on the nature of their surface.

4.6 Thermal Properties

Specific heat, thermal conductivity, and thermoelectric power are some of the superior properties peculiar to nanoparticles. For example, carbon nanotubes have anelevated thermal conductivity, close to a factor of 2 surpassing that of a diamond [19], implying that they are also tremendous conductors of heat. The thermal conductivity and specific temperature of nanotubes are mainly determined by phonons [32]. Phonons are lattice vibrations where the lattice of atoms or molecules oscillate uniformly at a specified frequency and are regarded as particles that carry vibrational energy like protons, i.e., they are a discrete quantum of vibrational mechanical strength [33]. Metal nanoparticles have raised thermal conductivity compared to most fluids in solid form and significantly enhanced thermal conductivity when nanometric solid particles are suspended in liquids (such fluids are called nanofluids). For instance, copper at room temperature has a thermal conductivity which is almost 700 times more than that of water and nearly 3000 more than that of engine oil. Alumina oxide hashigher thermal conductivity than that of water [23]. Hence, nanofluids are required to exhibit superior thermal conductivities relative to fluids containing microscopic-sized particles and the conventional heat transfer fluids. This is so because a larger surface area is better for heat transfer.

4.7 Vibrational Properties

The atoms in nanoparticles continuously vibrate to, and fro, each nanoparticle has a distinct set of vibrational motions called normal modes vibration, which is determined by the symmetry of the particles [19].

5.0 Applications of Nanoparticles

Nanoparticles represent changes in the 21st century with continuous advancements and progression with time and in knowledge [9]. The study of the advancement of nanoparticles has become top research as they play a crucial role in raising the standard of living and making life more comfortable through electronics, nanomedicine, nanofabrication, and other related nano-fields. Several engineering applications of nanoparticles, both current and anticipated, are outlined here [21].

5.1 Electronic Application

By utilizing individual molecules or nanotubes, nanoelectronics can be used to construct computer memory to store bits of information, nanotube transistors, nanotube integrated circuits, nanotube flat-panel displays, nanoscopic lasers molecular switches, switches, fast logic gates and nanotube electrodes in fuel cells [20]. Microelectronic fabrication is aimed at constructing nanoscopic electronic circuits such that the components containing these nano-processors could run faster and include more logic gates, thereby allowing computations to take place at extremely high speeds. Nanocrystalline materials can be used to enhance the resolution of televisions and monitors, and which may meaningfully lower cost. More so, flat-panel displays made with nanomaterials such as carbon nanotubes possess advanced brightness and contrast, in comparison to traditional screens owing to their high electrical and optical properties [34]. Owing to the increased reactivity and higher surface area associated with nanoparticles, they can be used as high-sensitive sensors for discovering variables such as capacitance, chemical activity, electrical resistivity, thermal conductivity, and magnetic permeability. The electronic application of nanoparticles is non-exhaustive as it can further be applied to produce high energy density batteries and for dada storage.

5.2 Ecological Applications

Among several promising applications of nanoparticles via nanotechnology, environmental improvement is one of them. Even though research into the ecological demands of nanoparticles is still at the infancy stage, it is progressing exponentially. The removal of heavy metals from groundwater has attracted noticeable attention due to their unfavorable effect on both human and environmental health. As a result, the ability of nanoparticles to react with toxic substances in the air, soil, and water and then reduce them to safe levels or completely transform into benign compounds is presently being studied [34]. The environmental applications of nanoparticles can be grouped into three categories:

1. Ecologically friendly or sustainable products such as pollution prevention or green chemistry [35].
2. Remediation of materials polluted with dangerous substances through absorptive remediation technology (removes pollutants by sequestration) or reactive remediation technology (involves degradation of pollutants, sometimes down to harmless products).
3. Sensors and detectors for environmental pollutants via the development of improved techniques for monitoring, detection, and decontamination of harmful biological agents [36-37].

Nanomaterials, through their refined chemical activity, can be used as catalysts to react with poisonous gases and pollutants such ascarbon monoxide and nitrogen oxide in automobile catalytic converters and power generation equipment[38]. This will help prevent ecological pollution from burning coal and gasoline. Inclusion, for water cleanup, iron nanoparticles coupled with traces of palladium are used to mutate harmful compounds in wastewater into less-toxic end products. For instance, water contaminated with organic chlorine and soil containing chlorine-based organic solvents are treated with nanoparticles that covert these harmful substances to solid hydrocarbons. Conversely, the increased application of engineered nanoparticles domestically and industrially has led to the release of such materials into the environment. Thus, evaluating the risk of these nanoparticles in the environment requires a detailed understanding of their reactivity, ecotoxicity, mobility, and persistence [23].

5.3 Applications in Energy Harvesting

Literature reveals that the limitations associated with fossil fuels are significantly due to their non-renewable nature, their forecasted scarcity in years to come, and greenhouse gas emissions. This has led scientists to shift their research focus in search of new strategies on how to generate less expensive energy and renewable energies production alternatives from readily available sources [23]. Research shows that nanoparticles are the ideal choice for this purpose owing to their excellent optical behavior, large surface area, and catalytic nature.

1. Nanoparticles such as carbon nanotube fuel cells are used in energy storage applications to reserve hydrogen [39].
2. The reduction of electrochemical carbon dioxide to solar cells, piezoelectric generators, and fuel precursors offer excellent sources for energy [5].
3. Nanoparticles such as reduced graphite oxide on titanium dioxide (TiO_2) nanorod arrays are aggressively being used in photocatalytic applications to generate energy from photoelectrochemical water splitting generation [40].
4. Through the construction of nanogenerators, piezoelectric can be used to convert mechanical energy into electricity [5].

5.4 Applications in Mechanical Engineering

The potential of nanoparticles to offer diverse applications in mechanical industries,especially in lubricants, adhesives, and coating applications, is evident from their outstanding mechanical properties such as young modulus, stress, and strain, as revealed in literature [23].Through the invention of nanodevices and systems,science and technology continue to progress.Several Microelectromechanical systems (MEMS) devices have been made and are in use commercially. For instance, in 2004, about 90 million units of accelerometers were installed in vehicles, 30 million units of silicon-based piezoresistive pressure sensors for manifold absolute pressure (MAP) sensing for car engines, 37 million units of capacitive pressure sensors for tire pressure measurements in 2005 [41],etc. Nanoparticles showimpressive physical and chemical properties and can be used to produce several materials to impart enhanced functionality (such as strength, hardness, resistivity to wear and corrosion) to engineered materials such as increasing the lifespan of components and automobile parts.

In manufacturing, nanocrystalline materials like tungsten carbide (C.W.) can be used to produce cutting tools for machining operations that are stronger than their traditional counterparts based on the presence of increased micro-hardness of nanosized composites. Also, inorganic materials made of nanosphere could be utilized as lubricants, thereby acting as nanosized ball bearings [42]. Furthermore, nanofluids due to their enhanced properties can be used in the automobile industry to improve the overall efficiency of cars by dispersing nanoparticles in radiator coolant or engine oil [43]. Car tires can be mechanically reinforced with carbon black nanoparticles ranging between 10nm to 500nm, which act as fillers in the polymer matrix of tires [34]. Nanoparticles have been used to control surface roughness and porosity of a diversified range of inorganic materials and polymers to produce fabrics that are resistant to stain and water, i.e., ultra-hydrophobic materials. They are used in coating textiles, for example, nylon to provide antimicrobial characteristics [42].

6.0 Nanotoxicology

Air quality scientists have long recognized ultrafine particles as having at least a single-dimensional aspect of 100nm or less and having properties worthy of special consideration of toxicological study.Humans are already being exposed to a range of natural and tailor-made nanoparticles in the air. Exposure through medical applications, food chain, and water supply are also likely possibly. In 2004, the study of the toxicity of nanoparticles was termed ‘nanotoxicology’ by inhalation scientists due to concerns resulting from the suitability of conventional toxicological assessment methods for evaluating engineered nanomaterials[44-45]. Nanotoxicology has recently been defined as the study of the adverse effects of engineered nanomaterials on living systems and ecosystems, including the prevention and amelioration of such adverse effects [46]. The Royal Society defines as "the study of phenomena and manipulations of materials at atomic, molecular and macromolecular scales, where the properties differ significantly from those at a larger-scale."

It has been recognized that the primary exposure of humans to nanoparticles as many other environmental substances is by inhalation, oral ingestion, or through the skin. Toxicologic studies on cells (i.e., bio-nano interactions) in Vitro and Vivo are essential in understanding the bio-distributions and toxic effects of many nanomaterials as these nanomaterials may amalgamate and form larger aggregates when in contact with culture solutions and biological fluids which can result in the compromised immune system and respiratory illness such as lung disease, coughing, wheezing and inflammation[47].Thus, humans are simultaneously being exposed to materials of varying sizes that could be made of single particles or agglomerates of particles.The prevention of toxicity from nanoparticles involves a practical risk assessment before products are commercialized. However, an effective and efficient risk assessment is only as functional as the research going into it [48].Scientists and toxicologists are continually working to understanding how nanoparticles disperse into the environment and affect living organisms, especially humans. They are also racing to develop new ways of testing these engineered nanoparticles or nanomaterials for potentially toxic effects. Unfortunately, nanotoxicology is an area that is not yet fully understood and requires further research on the behavior of these particles as our knowledge of their environmental concentration and effects on human health is lacking.

7.0 Justification

Though nanoparticles have been in existence before now,its earliest use dates to the fourth century A.D.,Where its renowned properties were first seen in a Roman cup called Lycurgus cup[49]. The cause of the effect gotten from the use of colloidal gold particles was unknown to the manufacturer at the time. In the last severaldecades, researchers and engineers have come to understand the reason behind the Lycurgus cup's unique optical characteristics.They continue to uncover other striking properties,both physical and chemical properties associated with nanoparticles, as well as ways in which these properties can be manipulated to achieve desired results in a wide range of applications[50], as stated in this review.

8.0 Conclusion

The physicochemical properties,preparatory methods, particulate size control,stabilization techniques, and toxicityof nanoparticles were discussed in this review. Nanoparticles due to their unusual and ecologically benign properties constitute the building blocks for numerousengineering applications. Controlling the size of these particles is what opens doors to new and unique uses, as it allows them to be influenced and fine-tuned to meet specific target applications, be it in pollution cleanup, renewable energy, or cosmetology. With raising new applications and endless possibilities of nanoparticles come budding new fields of study. One such area is nanotoxicology, which studies theadverse effects of novel nanomaterials on living systems, especially on human health and the environment. Unfortunately, the acceleratingadvancements and enormous growth in nanotechnology, coupled with the increasing use in everyday products, have surpassed the level of research data on the impact of engineered nanomaterials ENMs on terrestrial and aquatic ecosystems. To date, we have only touched the shallow end of lessons to learn and to comprehend the complex effects of these tinymolecules or ultrafine particles on cells, tissues, and organisms as a whole.

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Afolalu conceptualized the paper. All authors equally wrote the paper

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