IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

REVIEW ON NANOPARTICLES

N. Jagadeesh Kumar[1], R. Ravi Kumar[2]. A. Sarangapani[3]

[1]Assistant Professor in Physics, S.G.S Arts College, Tirupati, AP, India.

[2]Assistant Professor in Physics, S.V Arts College, Tirupati AP, India.

[3]Assistant Professor in Chemistry, S.V Arts College, Tirupati AP, India.

Abstract

Because they exceed their bulk counterparts in terms of tunable physical, chemical, and biological properties, nanomaterials (NMs) have become increasingly important in technological breakthroughs. NMs are divided into groups according on their size, make-up, shape, and place of origin. Each classification becomes more valuable as we become better at predicting the particular characteristics of NMs. Toxicological problems are unavoidable as NM production continues to develop and find more industrial uses. This review's objective is to compare artificially created (engineered) and naturally occurring nanoparticles (NPs) and nanostructured materials (NSMs) in order to pinpoint their unique nanoscale characteristics and pinpoint specific knowledge gaps regarding the evaluation of NPs and NSMs' environmental risk.

Keywords: nanomaterial classification, nanomaterial history, Nano toxicity, oxidative stress, reactive oxygen species, regulations

INTRODUCTION

An important area of study and a techno-economic sector with full expansion in various application domains are nanoparticles (NPs) and nanostructured materials (NSMs). Because they outperform their bulk equivalents in terms of tunable physicochemical properties including melting point, wettability, electrical and thermal conductivity, catalytic activity, light absorption, and scattering, NPs and NSMs have become increasingly important in technological developments. In the International System of Units (Système international d'unités, SI), a nanometer (nm) is a unit that corresponds to 109 metres in length. In theory, NMs are materials with at least one dimension having a length of 1-1000 nm; however, in practise, NMs are typically characterised as having a diameter between 1 and 100 nm.

However, there isn't a single, broadly acknowledged definition of NMs. The definition of NMs is a topic of disagreement among many organisations (1). NMs "may exhibit distinctive features dissimilar from the equivalent chemical component in a larger dimension," according to the Environmental Protection Agency (EPA) (2). NMs are also described as "materials that have at least one dimension in the range of about 1 to 100 nm and show dimension-dependent phenomena" by the US Food and Drug Administration (USFDA) (3). The International Organization for Standardization (ISO) and other organisations have similarly referred to NMs as "materials with any outward nanoscale dimension or possessing interior nanoscale surface structure" (4). This ISO definition has been used to describe terminology like nanofibers, nanoplates, nanowires, quantum dots, and others that are similar (5).

The EU Commission (6)defines the word "nanomaterial" as "a manmade or natural material that possesses unbound, aggregated or agglomerated particles with exterior diameters in the range of 1-100 nm." The British Standards Institution (7) recently offered the following definitions for the terminology used in science:

(i) Nano scale: a size range of roughly 1 to 1000 nm.

(ii) Nano science: The science and study of matter at the nanoscale that deals with comprehending their qualities that are reliant on their size and structure and contrasts the emergence of individual atoms or molecules or bulk material-related distinctions. Nanotechnology is the scientific method of manipulating and controlling matter on the nanoscale for different industrial and therapeutic purposes. Any substance that has internal or exterior structures on the nanoscale is referred to as a nanomaterial. Material with one or more peripheral nanoscale dimensions is referred to be a nano-object. A nanoparticle is a small, three-dimensional nanoscale entity. When a nano-longest object's and shortest axes are different lengths, the names "nanorod" or "nanoplate" is used instead of "nanoparticle" (NP).

(iii)Nanofiber: A nanomaterial is referred to as nanofiber if it has a third, bigger dimension in addition to two outer nanoscale dimensions that are identical. A multiphase structure called a nanocomposite has at least one phase with a nanoscale dimension.

(iv)Nanostructure: A structure made up of connected building blocks at the nanoscale. Nanostructured materials are defined as having either an interior or external nanostructure. The adoption of differing definitions in various jurisdictions presents a significant barrier to regulatory activities since it causes legal reluctance to use regulatory measures for identical NMs. Therefore, a significant obstacle to creating a unified international definition for NMs is the requirement to meet divergent considerations.

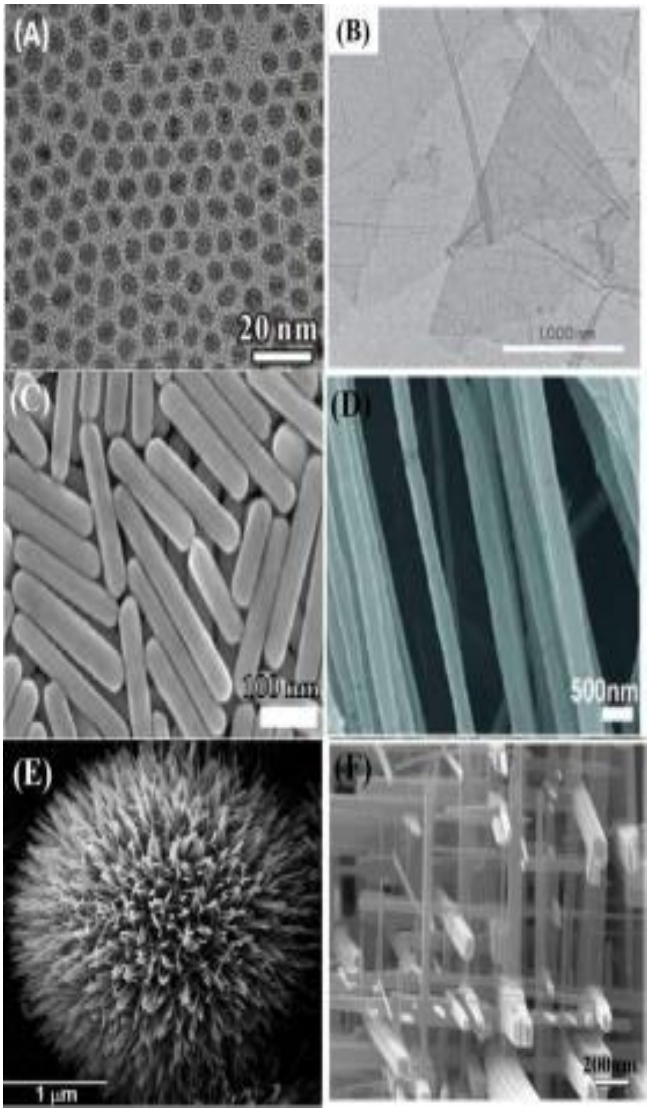
TYPES AND CLASSIFICATION OF NANOMATERIALS

Four material-based categories can be used to group the majority of current NPs and NSMs.

1. Carbon-based nanomaterial’s: These NMs often contain carbon and can take the form of spheres, ellipses, or hollow tubes. The group of carbon-based NMs consists of fullerenes (C60), carbon nanotubes (CNTs), carbon nanofibers, and carbon black, graphene (Gr), and carbon onions. With the exception of carbon black, the main production techniques for these carbon-based compounds include laser ablation, arc discharge, and chemical vapour deposition (CVD) (8).

2. Nanomaterial's with an inorganic basis: such as metal and metal oxide NPs and NSMs. These NMs can be synthesised into ceramics, metal oxides, semiconductors, such as silicon, and metal NPs, such as Au or Ag.
3. Organic-based nanomaterials: These are NMs made primarily from organic matter, as opposed to NMs made from carbon or other inorganic materials. The self-assembly and design of molecules with the aid of noncovalent (weak) interactions enables the transformation of organic NMs into desirable structures including dendrimers, micelles, liposomes, and polymer NPs.
4. Nanomaterials based on composites: Composite NMs are multiphase NPs and NSMs with one phase on the nanoscale dimension. They can either combine NPs with other NPs or NPs with larger or bulkier materials (for example, hybrid nanofibers) or more complex structures, like metal-organic frameworks. Any combination of carbon, metal-, or organic-based NMs and bulk materials made of metal, ceramic, or polymer may be used to create the composites.

FIG 1: NANOPARTICLES



A. Non porous
B. Nano sheets
C. Nano rods
D. Nano fibers
E. Nano wires
F. Nano wires network

CLASSIFICATION OF NANOMATERIALS BASED ON THEIR DIMENSIONS

Numerous nations' economies are currently being helped and will continue to be helped by the nanoscale manufacture of conventional goods. NPs and NSMs come in a wide variety of forms, and more are expected to develop in the future. As a result, the time is now for their classification. (9) proposed the initial concept for NM classification. Here, NMs were categorised according to their chemical make-up and crystalline morphologies. The dimensionality of the NPs and NSMs, however, was not taken into account, hence the Gleiter scheme was not entirely comprehensive (10). The electron flow along the dimensions in the NMs has a significant impact on this classification. For instance, 1D NMs have electrons that can move along the x-axis, which is less than 100 nm, but 0D NMs have electrons that are confined in a dimensionless environment. The categorization value of NMs is based on their ability to be predicted in terms of their attributes. According to Gleiter's classification, the "grain boundary engineering" idea, the properties of NMs are highly dependent on the grain boundaries. Therefore, grain boundary engineering will increase the traditional inner size effects, such as melting point lowering and diffusion augmentation. According to the "surface engineering" approach and the classification of Pokropivny and Skorokhod, the properties of NMs are related to the particle shape and dimensions.

ORIGIN

NPs and NSMs can be divided into natural and synthetic categories in addition to classifications based on dimension and material.

1. Natural nanomaterials are created by biological species or by human activity in the environment. Natural resources can easily be used to create artificial surfaces with unique micro- and nanoscale templates and features for technological applications. Regardless of human activity, naturally occurring NMs exist in all of the Earth's spheres (including the hydrosphere, atmosphere, lithosphere, and even the biosphere). Earth is made up of naturally occurring materials (NMs) that are found in each of the planet's spheres, including the atmosphere, which includes the entire troposphere, the hydrosphere, which is made up of oceans, lakes, rivers, groundwater, and hydrothermal vents, the lithosphere, which is made up of rocks, soils, magma, or lava at specific stages of evolution, and the biosphere, which includes lower organisms like bacteria and higher organisms like humans (11).

2. Synthetic (designed) nanomaterials can be created through physical, chemical, biological, or hybrid means as well as through mechanical grinding, engine exhaust, and smoke. The use of engineered NMs in consumer goods and industrial applications, as well as their growing manufacturing and subsequent release, has raised the issue of risk assessment methodologies recently. The behaviour and outcome of manufactured NMs in various environmental media can be predicted with great accuracy using these risk assessment methodologies. The main issue with designed NMs is determining if current information is sufficient to predict their behaviour or if they behave differently from wild NMs in relation to their surroundings. Engineered NMs are now produced using a variety of sources that are relevant to possible applications (12).

HISTORY AND DEVELOPMENT

More than 4,500 years ago, humans began taking advantage of the reinforcing capabilities of ceramic matrixes by incorporating natural asbestos nanofibers (13). Based on a synthetic chemical procedure to create PbS NPs with a diameter of around 5 nm for hair colour, the Ancient Egyptians were also employing NMs more than 4000 years ago (14). Similar to "Egyptian blue," which was created and utilised by Egyptians using a sintered blend of nanometer-sized glass and quartz in the third century BC (15), "Egyptian blue" was the first synthetic colour. Egyptian blue is a complex combination of the minerals CaCuSi4O10 and SiO2 (both glass and quartz). Archaeological research has revealed that Egyptian blue was widely used for decorative purposes in ancient Roman Empire regions, including nations like Egypt, Mesopotamia, and Greece.

When Egyptians and Mesopotamians began employing metals to make glass in the 14th and 13th centuries BC, it may be said that the period of metallic nanoparticles began. Since then, metallic NPs have been synthesised via chemical processes (16). These substances could be the first synthetic NMs to be used in a real-world setting. Frattesina di Rovigo (Italy) has discovered red glass from the late Bronze Age (1200–1000 BC) that is tinted by the surface plasmon excitation of Cu NPs (17). Similar to this, it has been stated that the Celtic red enamels from the 400–100 BC era include Cu NPs and cuprous oxide (cuprite Cu2O) (18). However, the most well-known use of ancient metallic NPs is on a piece of Roman glass.

The Lycurgus Cups are a type of dichroic glass from the fourth century AD that changes colour depending on the direction of light, turning red when it comes from behind and green when it comes from the front (19). According to recent research, the Lycurgus Cups contain roughly 10% Cu as well as Ag-Au alloy NPs with a 7:3 ratio (20). Later, colloidal Au and Ag NPs were used to create the red and yellow stained glass that can be found in mediaeval churches (21). Mesopotamians first began utilising glazed ceramics for metallic lustre designs around the ninth century (22). Due to the presence of discrete Ag and/or Cu NPs isolated inside the outermost glaze layers, these decorations displayed amazing optical characteristics.

These ornaments are an illustration of metal nanoparticles that, under specific reflection circumstances, exhibit iridescent vivid green and blue colours. A double layer of Ag NPs (5-10 nm) in the outer layer and larger ones (5-20 nm) in the inner layer were found in these ceramics after TEM investigation. The separation between the two layers was found to be constant at 430 nm, which led to interference effects. Phase shift results from light scattering from the second layer, which is caused by light scattering from the first layer. Later, this method was used to produce red glass all over the world. A similar process was employed in Japan in the middle of the 19th century to create the well-known Satsuma glass.

SOURCES

Based on where they come from, sources of nanomaterials can be divided into three main groups: There are three types of nanomaterials:

(i) incidental nanomaterials, which are created accidentally as a byproduct of industrial processes, such as nanoparticles made from welding fumes, combustion processes, and even some natural processes like forest fires;

(ii) Engineered nanomaterials, which have been created by humans to have specific desired properties for desired applications; and

(iii) Naturally produced nanomaterials, which can be found in the bodies of organisms, in soil, and in water. The lines between produced, incidental, and naturally occurring NPs, however, are frequently muddled. For instance, incidental NMs may occasionally be regarded as a subtype of natural NMs (23).

Atoms, the fundamental building blocks of all naturally occurring living and nonliving creatures, make up molecules. Multiple natural manipulations of atoms and molecules have produced complex NPs and NSMs that continue to support life on earth. The distribution of incidental and naturally occurring NMs in ground and surface water, the oceans, continental soil, and the atmosphere is ongoing. The morphology of engineered NMs may typically be better regulated than that of incidental NMs, which is one of the key differences between the two types of NMs ***(24)***. Additionally, engineered NMs can be specifically created to take advantage of novel properties resulting from their small size.

TOXICITY

As NPs are created by natural processes, humans are exposed to them (25). The main causes of the release of nanoparticles in their original or modified forms into the environment are the production, use, disposal, and waste treatment of items containing nanoproducts. Human epidermis typically protects against external chemicals, while the lungs and gastrointestinal system are vulnerable organs. NPs are around the size of viruses. The human immunodeficiency virus (HIV) particle, for example, has a diameter of about 100 nm (26). Inhaled NPs can easily enter the bloodstream and other parts of the body, such as the liver, heart, or blood cells.

The general characteristics of NPs that are used to categorise them include dimensionality, composition, morphology, aggregation, and homogeneity. Similar to free NPs, nanostructured thin films and fixed nanoscale circuits in computer microprocessors all have key distinctions that make it simpler to categorise them for specific applications. Free NP movement is unrestricted, which makes it simpler for them to spread across the environment and pose a potential health danger when exposed to people. On the other hand, handling fixed NPs properly poses no health danger because the nanostructured components are affixed to a substantial object. Asbestos is a prime example of a material whose main states are safe in this situation. It is also important to remember that the main causes of nanoparticle toxicity are the chemical makeup and form of the particle.

TABLE 1: RISK FACTORS OF NANOPARTICLES

PROPERTIES OF NANOPARTICLES	RISK ASSESSMENT
Agglomeration or aggregation	Weakly bound (agglomeration) and fused particles are important risk factors because they cause NMs to lose their ability to resist corrosion and become highly soluble. (27), (28). Weakly bound (agglomeration) and fused particles are important risk factors because they cause NMs to lose their ability to resist corrosion and become highly soluble.
Recycling And Disposal	NMs are not required to follow any strict safe disposal guidelines. The experimental outcomes of NP exposure are unknown, and its possible toxicity is still up for debate. As a result, policies for long-term disposal and recycling have yet to be developed to address the uncertainty of a nanomaterial's effect.
Reactivity Or Charge	NPs can be charged through spontaneous derivative reactions or functionalization. The unique functionality and bioavailability of NMs will be significantly influenced by chemical species and their charge-related essential functional groups (28).
Impurity	Because of their high reactivity, NPs interact with contaminants by nature. Encapsulation becomes essential for solution-based NP synthesis as a result of this (chemical route). The reactive nano-entities are contained by nonreactive species during the encapsulation process to give the NPs stability.
contaminant dissociation	The presence of undissolved contaminants in the NP is regarded as a significant risk factor. For instance, depending on the precursor ($FeCl_3$ or $Fe_2(SO_4)_3$) utilised in their

	manufacture, sulphur impurities may be present in iron oxide nanoparticles (NPs). Similar metal impurities may be found in carbon nanotubes (CNTs) (29), (30) that are adsorbed on the CNT surface, such as nickel, yttrium, or rubidium.
Size	The main factor affecting NPs' reactivity and agglomeration is their particle size. It is well knowledge that smaller particles will experience slower rates of agglomeration. It is impossible to keep the NPs' original size after synthesis. As a result, encapsulation in NP synthesis becomes virtually inevitable. By classifying NPs according to their particle size, the exceptional size-dependent chemistry of NPs is distinguished from classical colloid chemistry (31).

The toxicology of NMs is dependent on a number of variables, including:

Effect of Exposure Duration and Dose

The molar concentration of NPs in the surrounding media multiplied by the exposure period directly affects how many NMs enter the cells (24).

The Impact of Accumulation and Concentration

The toxicity of NPs at various concentrations has been the subject of numerous conflicting reports. Aggregation is encouraged by an increase in NP concentration. Since the majority of NP aggregates are only a few micrometres in size, they may not be able to infiltrate cells in large enough quantities to retain their toxicity.

Impact of Particle Size

Size-dependent toxicity is shown in NPs. Compared to Ag+ ions and Ag NPs with larger diameters (20-100 nm), Ag NPs with a diameter of less than 10 nm have a greater ability to enter and disrupt the cellular systems of many organisms (32).

Effect of Particle Shape

NPs have shape-dependent toxicity, meaning that toxicity levels vary depending on the aspect ratio. Asbestos fibres, for instance, can induce lung cancer at a length of 10 m, mesothelioma at a length of 5 to 10 m, and asbestosis at a length of 2 m (33).

Effect of Surface Area

The toxicological impact of NPs typically grows as surface area and particle size decrease. Additionally, it should be emphasised that human cells respond differently to nano- and micro particles at the same mass dose.

Effect of Crystal Structure

NPs may display various cellular uptake, oxidative processes, and subcellular localisation depending on the crystal structure (34). Effect of surface functionalization. The translocation and subsequent oxidation processes have had a dramatic impact on the surface characteristics of NPs (35), (36).

DISCUSSION

Nanomaterials have traits including strong chemical bioactivity and reactivity, the capacity to penetrate cells, tissues, and organs, and increased bioavailability. Because of their distinctive qualities, NMs excel in biomedical applications. These advantages, meanwhile, potentially present a risk of toxicity. As a result, various government entities have enacted regulations via legislation, laws, and rules to reduce or eliminate concerns related to NMs (37). However, there are no particular worldwide regulations, protocols, or legal definitions for the manufacture, processing, or labelling of NPs, their toxicity testing, or their effects on the environment. To address the entrance of NMs into the biomedical area, medical norms pertaining to ethics, environmental safety, and medical governance have been modified (38), (39). In order to limit the possible risks of NMs, the USA and the European Union (EU) already have robust regulatory structures and directive legislation. The European Commission has created a number of pieces of technical advice and EU legislation that specifically mention NMs. This legislation has been used within the EU to ensure legislative consistency and to ensure that a NM used in one industry will also be treated as such when it is used in another industry. "A natural, incidental, or manufactured material containing particles, in an unbound state, as an aggregate, or as an agglomerate, and where for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range of 1 nm to 100 nm," is what the European Commission defines as a "nanomaterial." The rules of these laws apply because the specifications of the materials and products comply with the substance definitions set forth by the European Chemical Agency (REACH) and the European Classification and Labelling of Chemicals (CLP) (40).

Similar strategies are covered in the Nanomaterials Policy Recommendations report for reducing or eliminating the danger of NMs in industries related to food. Additionally, according to this research, businesses should create a thorough public policy for the use of NMs, publish NM safety evaluations, establish supplier requirements, label NPs less than 500 nm, and use a hazard control strategy to avoid exposure to NPs (41). The use of engineered NPs in food has already been prohibited by organic suppliers like the UK Soil Association (42), the Biological Farmers of Australia (43), and the Canada General Standards Board (44).

CONCLUSION

In recent years, toxicity profiling of NMs has been one of the most in-demand study areas globally. Natural NMs have been a part of the ecosystem for a long time, and they contain some processes that make them less damaging to living things. Research breakthroughs have discovered some immediate hazardous impacts of nanosized particles in living systems, though. It is clear from this review study that NMs from human activities and NMs created for use in consumer products can have hazardous effects on living things. Additionally, to define safe application techniques and dose levels, new NPs such viral NPs and nanozymes need undergo stringent cytotoxicity experiments. Many nations have enacted laws and regulations to reduce or eliminate the potential risks of engineered NMs in consumer goods. To recognise and stay away from toxic NPs, there must be extensive research in the field of nanotoxicology and stringent regulations by government organizations.

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