The entrancing world of nanoparticle research

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Abstract

Nanoparticle research is an enthralling field of study. Nanoparticles' strongly size-related features open up a plethora of possibilities for unexpected discoveries. Nanoparticles' often surprising and unprecedented behaviour has a lot of promise for new technological applications, but it also creates a lot of hurdles for scientists. In order to explain the experimental findings, they will need to develop highly controllable synthesis processes, more sensitive characterization tools, and finally new models and theories. Our goal in writing this review is to provide an overview of the current state of nanoparticle research, based on a selection of papers that we have found to be particularly illuminating.

Medical nanodevices, such as drug administration, imaging, and diagnosis, can be made with nanoparticles (NPs). Developing NPs that are perfect for a specific purpose necessitates an understanding of the many types of NPs and their qualities.

Keywords: Nanoparticles, . NPs properties, Types of NPs, Preparation of NPs.

1. Introduction

The history of nanoparticles is lengthy and storied. Both current research and man-made materials aren't the exclusive sources of these ideas. Inorganic and organic nanoparticles are produced by weathering, volcano eruptions, wildfire and microbiological processes [1], [2]. There is no doubt that nanoparticles have been around for a long time and so have a rich history of application. In comparison to the 4500-year-old controlled reinforcement of ceramic matrix with natural asbestos nanofibers, the utilisation of clay minerals as natural nanomaterials appears to be less progressed [3]. Gloss and glass technologies, on the other hand, have achieved the most stunning effects when using metal nanoparticles as colour pigments]4, 5. 9th-century Mesopotamian pottery with metallic lustre decoration on the surface. To achieve their outstanding optical properties [6], these embellishments had silver or copper nanoparticles dispersed throughout the glaze's uppermost layers.

An busy area of research, as well as a developing sector of technology and economics, is focused on nanoparticles and nanostructured materials (NSMs). They have gained importance in technological advancements because of their adjustable physical and chemical properties, including as melting point, wettability and electrical and thermal conductivity, catalytic activity, light absorption or scattering. nm is an abbreviation for nanometer, which is one billionth of a millimetre in length according to the SI. It is theoretically possible for NMs to have a length of 1–1000 nm, however they are typically characterised as having a diameter of 1–100 nm. The European Union has a number of laws that refer to NMs (EU)and the United States today. However, there is no single universally accepted definition for NMs. When it comes to defining NMs, different groups have differing viewpoints. "NMs can exhibit distinct features unrelated to the comparable chemical component in a greater dimension," according to the Environmental Protection Agency (EPA).

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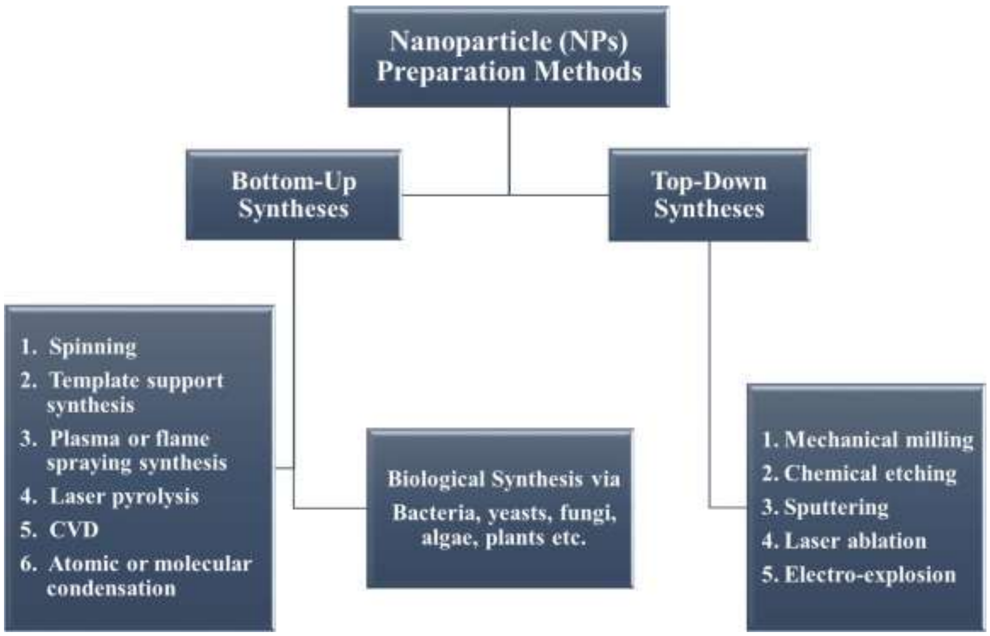

Figure: 1. Nanoparticles: Properties, applications and toxicities.

1. NPs properties

In vivo, the properties of the NPs have an impact on how they behave. Morphological features like as shape and size, in particular, can have an impact on NP circulation and targeting in the body28,29. Variations in NP breakdown rates and drug release kinetics can also be attributed to these properties30. Specific cell signalling is influenced by the shape and size of NPs31. Surface characteristics of NPs, as well as the presence or absence of targeted ligands, can have an impact on NP behaviour in biological systems32,33. Because all of these NPs' properties are intertwined, determining which one will produce a specific biological effect is difficult. Furthermore, minor changes in just one of these qualities might cause massive changes in the performance of the other NPs.

1.1 Size and polydispersity index

NPs should ideally circulate till they reach their intended anatomical spot. The immune system is able to assist in the eradication of NPs because the reticulum endothelial system recognises them. (RES) On the other hand, mechanical filtration by the lung, liver, kidney, or spleen can remove NPs. The size of the particles is an important consideration in particle removal. The lungs' capillary network has been found to mechanically filter and entrap MPs larger than 7 metres (m)35,36. Particles phagocytized by Kupffer cells or spleen macrophages are detected by the RES in the liver or spleen, respectively, and range in size from 0.1 to 7 m. To avoid macrophage absorption or recognition, particles with diameters of less than 100 nm will remain in the endothelium-lined blood vessels for longer periods of time39. Smaller nanoparticles, those with a diameter of less than 6 nm, are filtered out of the kidneys by the glomerular filtration process.

1.2. Shape

Recent research has revealed that particle shape (sphere, ring, disc) has a substantial influence on NP circulation, distribution within the body, cellular uptake, and general in vivo behavior34,48,49. Several

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studies have looked at the influence of shape on NP transport throughout the human body39,50,51. While spherical particles can travel freely, irregularly shaped particles have a considerably higher chance of aligning or tumbling in vessel bifurcations or filtering organs50. A spherical particle must be less than 200 nm in diameter to pass through the spleen52. It can pass through this organ52 if it is a disk-shaped object with a diameter of roughly 7 m and a height of 150 nm.

1.3. .Surface properties

Hydrophobicity and surface charge are two surface attributes that have been utilised to describe NPs55,56. Hydrophobicity is important because it effects NP clearance from the body as a result of RES activity. In fact, when hydrophobicity decreases, so does the number of non-specific interaction of proteins. This results in a decrease in the ability of macrophages to phagocytose. One way to think about it is to say that the electrical potential on the surface of nanoparticles (NPs), also known as surface potential, dictates how likely it is that the particles will aggregate in a given medium. As the absolute value of this surface electric potential increases, the repulsion between NPs becomes more pronounced. When compared to neutral or negatively charged NPs, positively charged NPs are more non-specifically absorbed.

1.4. Targeting

In contrast to other alternative medicines, it is hoped that NPs will be able to target a specific anatomical spot after injection, reducing negative effects on healthy tissues. Targeting tactics, both passive and active, can be utilised to attain this purpose. Passive targeting alters the NPs' properties by modifying their physicochemical/structural properties at the target site. Smaller nanoparticles can, for example, take advantage of tumours' leaky vasculature-induced increased permeability and retention mechanisms61. When NPs are targeted using active targeting, molecules are attached to the surface of the NPs. Monoclonal antibodies, protein peptides, sugars and nutrients are all examples of these molecules. Aptamers are also included. By exploiting particular interactions between molecules found in different tissues, cells or organelles throughout the body as well as NPs' surface molecules, the active targeting technique can be used to identify and target specific organelles, tissue types or cell types.

2. Types of NPs

NPs (diagnostic, imaging, or therapeutic) are shown in Figure 3 based on their intended use (diagnostic, imaging, or therapeutic) (i.e., diagnosis, imaging, or therapy). Organic and inorganic NPs make up the bulk of this section. There are dendrimers, liposomes (hybrid and compact polymeric NPs), and polymeric NPs in the first group. Micelles In the second group are fullerenes, quantum dots, silicon, and gold NPs.

Micelles, which are nanostructures, are created using amphiphilic compounds, such as polymers or lipids. While the hydrophobic groups are obscured, the hydrophilic groups can be seen clearly in the water Alternatively, they may undergo structural changes if exposed to lipid-rich environments. Micelles can be loaded with amphiphilic pharmaceuticals, which have their polar groups close to the hydrophilic groups of the hydrophobic core, whereas weakly water-soluble medications can be loaded into the hydrophobic core. Micelles are stable and circulate for a long time in the blood because of their hydrophilic shell.

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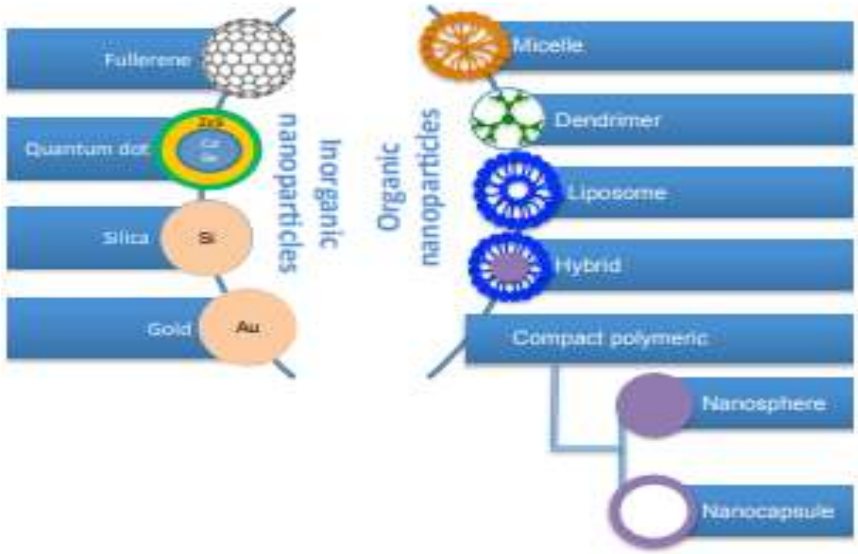

Figure: 2. Main types of NPs used in various applications; image not at scale.

2. Nanoparticles applications

When considering possible applications for nanoparticles, many people immediately picture a high-tech product. The fact that nanoparticles have been employed in everyday life for decades isn't surprising to anyone. A notable example of this is the colour carbon black. At 20–50 nanometers, the amorphous powder is formed. An astounding 10 million metric tonnes of industrial output are produced each year. Tyres in particular benefit from carbon black's ability to harden rubber. In the case of incomplete combustion of heavy aromatic oil or natural gas, it is produced.

It is also possible to incorporate nanoparticles into food products in a whole new way. They can be used as an anti-caking component in powdered goods (e.g., instant soup) and thickening pastes to keep them running smoothly. Traditionally, amorphous silica has been referred as as Adhesive E551.

Another common application for nanoparticles is in cosmetics, particularly sunscreens. Because nanoparticles of titanium dioxide and zinc oxide are colourless and more effective at reflecting and scattering UV rays than larger particles of the same material, they are commonly used in sunscreens. Nanoparticles that are smaller and more transparent appeal to the general public while also providing superior protection for human skin from the damaging effects of ultraviolet radiation.

To this day, optical effects are still a common application for nanoparticles, even though they've been around since antiquity. The multiple coats of paint on a car are a fantastic instance of this. Second to the base coat is the clear coat, which protects the paint from the outdoors.

3. Preparation of nanoparticles

Top-down or bottom-up approaches can be used to create nanoparticles in the laboratory. Cutting larger pieces into smaller ones until only nanoparticles remain is called "nanocutting," while "preparing" them is called "nanoprep." The most common method is lithography or etching, however grinding in a ball mill is also a possibility. Nanoparticles can be "produced" from simple molecules using a bottom-up approach, which is preferable for commercial production. The size of a nanoparticle can be controlled in a number of

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ways, including by limiting its concentration, functionalizing its surface, or using a micelle as a template. The bottom-up method controls particle size by using supersaturation.

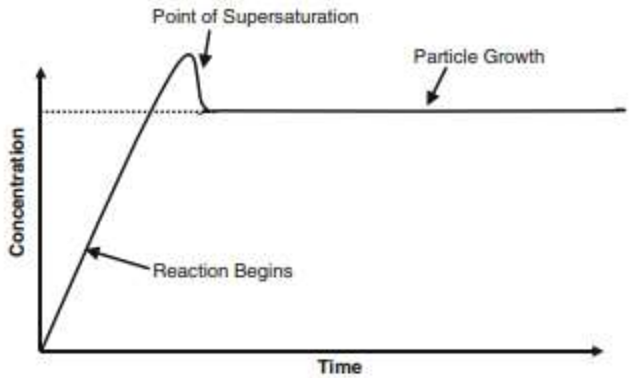

Figure: 3. A diagram showing a simplified summary of nanoparticle particle formation.

There is insufficient space here to consider all the permutations; however we will discuss some of the common methods employed in preparing the major classes of nanomaterials.

4.1. Metal oxides

Oxide nanomaterials can be made using a variety of methods, the most common of which are stabilised precipitation and flame pyrolysis. Here, we'll discuss why Titania is an excellent choice (TiO2). The sulphate procedure or aerial oxidation of titanium tetrachloride are the two most common ways to produce titanium dioxide pigments. Nanoparticles of titania have been prepared via hydrolysis of titanium alkoxides with the addition of a capping agent (Hague and Mayo 1994; Dhage et al. 2003). Additional control over size and surface functionalization can be gained by employing these methods. The TiO2 nanoparticles can also be produced by oxidising TiCl4 solution in a flame (Tsantilis et al. 2002).

4.2 Polymers

Polymer nanoparticles are most commonly made by a process called emulsion polymerization. In this technique, sodium dodecylsulfate (SDS) and a non-solvent (water) are used to emulsify styrene (for example) (Shim et al. 2004; Pons et al. 1991). Free-radical polymerization is initiated by the use of an ammonium persulfate-based initiator, and the final particle size is constrained by the micelles' diameter It is usual for the nanoparticles at the ends of polymer chains to contain trapped radicals because of the rapid reaction. The surfactant in the polymer particles is trapped by long aliphatic chains grafted onto or entangled in the polymer network. Polymer particles generated by this process also contain the surfactant as a result of the radical side reactions. On the other hand, the charge on these atoms tends to be stable..

4.3. Particles other than helium

Polymer- and oxide-based nanoparticles appear to be rare. Several of them have been made using stabilised precipitation or micelle templating. This can be seen in the formation of cadmium sulphide nanoparticles. Create these particles by using a precursor like cadmium chloride or sodium sulfuride, or by using an organic metal precursor (Christian and O'Brien, 2005; Trindade et al., 2001; Dios et al. 2005). 2001;

Trindade and coauthors). As a result of the development of hydrophilic particles, hydrophobic particles may now spread more readily in water (Winter et al. 2005). Micelles are used to form these particles, and as long as the surfactant isn't integrated into the crystal lattice, it can be removed through repeated washing or extreme dilution.

4.4. Nanowires and nanotubes

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4. Conclusion

As nanoparticles are so tiny, their distinctive and frequently surprising qualities have aroused a lot of curiosity. Despite the fact that some of these phenomena have been employed in materials technology for millennia, nanoscience and nanoparticle studies are just getting started. New nanomaterials can still be synthesised and new effects can still be discovered. Moreover, new models and concepts can be developed to describe and interpret the experimental results. As a result of their great potential, nanoparticles have gone from being a scientific curiosity to the centre of technical interest.

Despite the rapid advancements in the NPs sector in recent years, many modifications are still required before these medical devices may be used on a regular basis. As an example, determining the size of NPs after their synthesis under specified process conditions is a critical difficulty for developing highly reproducible treatments. Another flaw in this study is that it did not go into great detail on how alterations in the manufacturing parameters affect the properties of NPs.

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