NANOWARE Curriculum

MODULE 3: NANOPARTICLES

DELIVERABLE: R1/T1.1

31.10.2022

ASOCIATIA DIRECT

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Project Number: 2021-2-PL01-KA220-SCH-000051200

Co-funded by the European Union

Contents

1. Introduction to the Module

This module will explore the topic of nanoscience, what nanoparticles are, how to identify them, and describe some of their properties and uses to understand the importance of nanotechnology in society.

Nanoscale science is an exciting area of current research. Applications in information technology, medicine, composite materials, and other fields are now open for further exploration. Nanoscience is emerging as a way to describe the behavior of substances in biology, chemistry, physics, earth science, metrology, medicine, and engineering, having a huge impact on our daily lives.

Description

Nanoscience is one of the most important research projects in modern science. Nanotechnology is beginning to allow scientists, engineers, chemists, and physicians to work at the molecular and cellular levels to produce important advances in the life sciences and healthcare.

The learning material examines the recent advances in nanotechnology. Teachers will have the opportunity to explore Nanoscience methodologies to support student-centric activities in research and discovery learning. In addition, students will learn about nanoparticles as useful substances, being used to address lots of our health and technological problems.

This module focuses on the size of nanoparticles.

After completing this module, students will be able to:

- acquire a practical understanding of what nanoparticles are, how to identify them, and describe some of their properties and uses.

- be able to describe some of the most important and well-known applications of nanoparticles.

Module Goals

This module highlights the various tools for diverse applications in areas such as electronics, photonics, shape-memory alloys, biomaterials and biomedical nanomaterials, graphene-based technologies, and textiles and packaging. The topic addresses safety, economics, green production, and sustainability.

Learning materials increase the possibility of developing even more versatile materials that can be fine-tuned for specific applications at both experimental and theoretical scales.

Special attention is paid to sustainable approaches that reduce costs in terms of chemicals and time consumption. The module covers research trends, challenges, and prospective topics as well.

Learning Objectives

Students will be able to explain the specifics of Nanoparticle structures, and shapes, comparing nanoparticles with more familiar everyday objects to understand their almost unfathomably small size.

Students will learn about how to identify nanoparticles, describe their properties and uses, being able to compare dimensions of 1–100 nm to atoms, molecules, particles, and everyday objects to appreciate the relative size of nanoparticles. Students will:

- transfer mathematics skills to express nanoparticle sizes using scientific notation and calculate volumes and ratios,
- use calculations to analyze the effect size has on the surface area to volume ratio of particles,
- link properties of nanoparticles to their uses to understand the importance of nanotechnology in society,
- list uses of nanoparticles and the associated potential risks.

Learning Outcomes

This module refers to different types, sizes and shapes of nanoparticles.

It is designed to generate interest in math, science, and engineering programs among school students.

On successful completion of this module, learners should be able to:

- Recognize the types of nanoparticles
- Understand the best practices in using nanoparticles
- Present the importance of

Students will have a deeper understanding of the importance of best practices in using nanoparticles.

Estimated seat time

About 90 minutes or equivalent of one standard classroom hour is needed to complete this module in a classroom of 20-25 students.

2. Nanoparticles

This module will explore the topic of nanoscience, what nanoparticles are, how to identify them, and describe some of their properties and uses. The teacher will explain the concept of nanoparticles.

Nanoscale science is an exciting area of current research. Applications in information technology, medicine, composite materials, and other fields are now open for further exploration. Nanoscience is emerging as a way to describe the behavior of substances in biology, chemistry, physics, earth science, metrology, medicine, and engineering. It is a truly interdisciplinary field that can be the basis for the development of new, even revolutionary technologies of all kinds. These little particles and devices may soon have a huge impact on our daily lives.

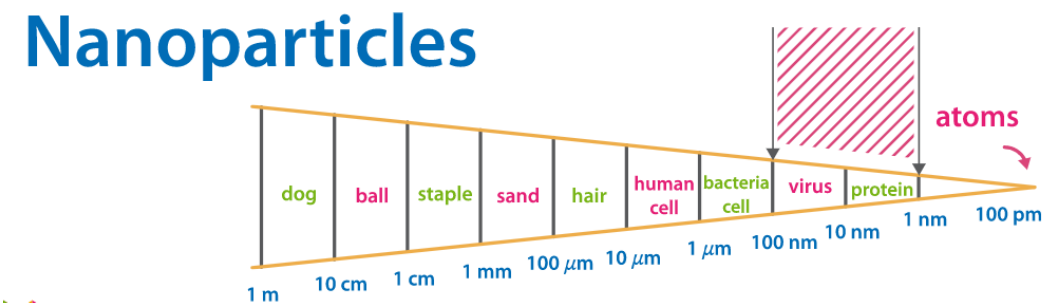

Figure 1. Nanoparticles
(Source: https://www.nagwa.com/en/videos/862104760473/)

Nanoscience is the study of the behavior of objects at a very small scale, roughly 1 to 100 nanometers (nm). One nanometer is one billionth of a meter, or the length of 10 hydrogen atoms lined up. Nanosized structures include the smallest human-made devices and the largest molecules of living systems.

Nano-, in everyday language, indicates that something is very small, even smaller than the micro-version. Nanoparticles can contain just one type of element or atom or multiple elements and types of molecules. Nanoparticles usually contain a few hundred atoms. They almost always have unusual physical and chemical properties because they are tiny and have such incredibly high surface-area-to-volume ratios.

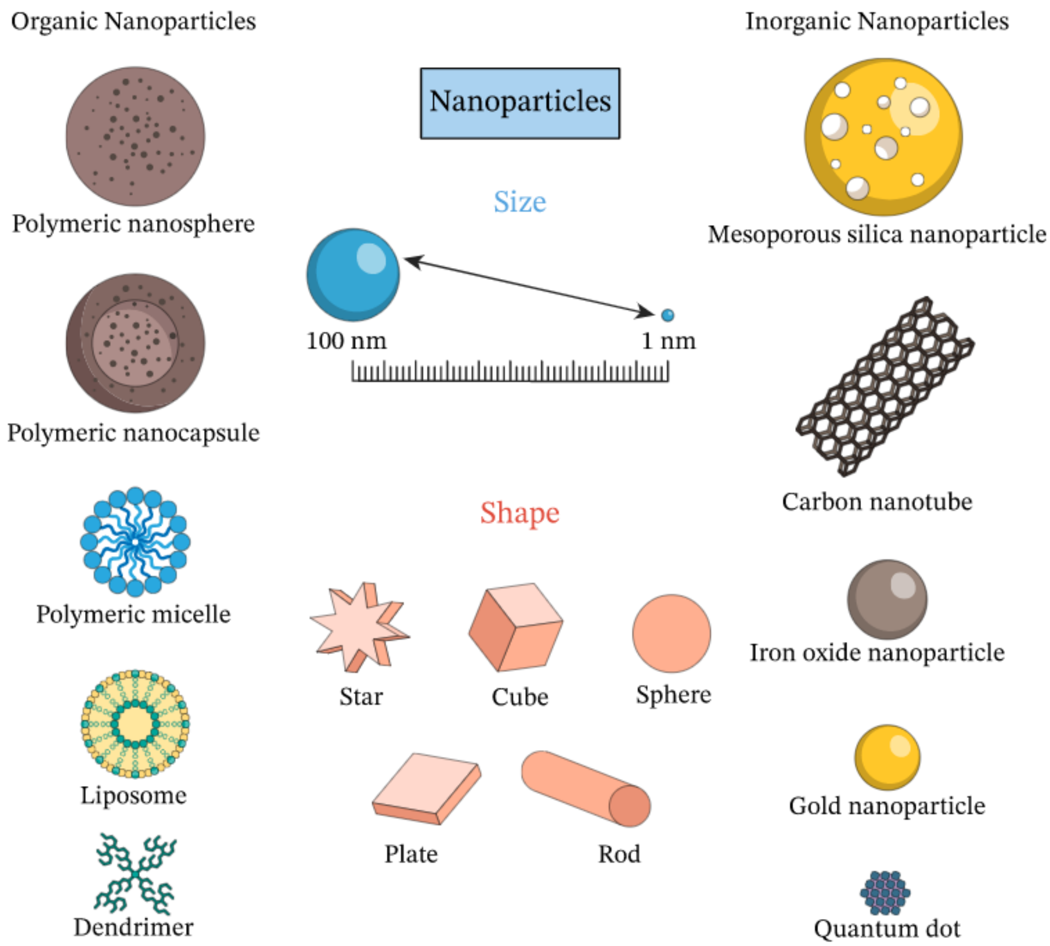

Figure 2. Shapes of nanoparticles
(Source: https://www.nagwa.com/en/videos/862104760473/)

Looking at the evolution of technology all around us, we'll notice that it's continually getting smaller. What about nanometer-sized particles?

Particles don't have a restricted size. Instead, scientists use the word nanoparticle to describe anything that's roughly evenly shaped and between one and 100 nanometers in height, width, and depth.

Nanoparticles must fit inside a box that's 100 nanometers by 100 nanometers by 100 nanometers. Almost any solid substance could be transformed into a nanoparticle.

Teachers will explain what nanoparticles are and how to describe them. Students will learn to act on the topic proposed.

- Scientists use the word nanoparticle to describe anything that is roughly evenly shaped and between one and 100 nanometers in height, width, and depth.
- We could make nanoparticles of salt, gold and even of wood. Some nanoparticles are single molecules. There's a form of carbon called buckminsterfullerene, which is a perfect shell of 60 carbon atoms that's about one nanometer across.
- Nanoparticles are hundreds of times smaller than fine particles and thousands of times smaller than coarse particles.

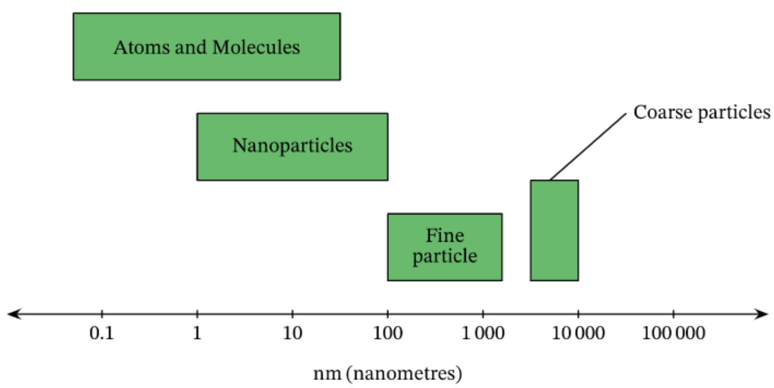

Figure 3. Nanoparticles
(Source: https://www.nagwa.com/en/explainers/640142370207/)

Fine and coarse particles are microscopic particles that are suspended in the air. Fine particles include substances like smog and soot. Coarse particles include substances like cement dust and mould spores. Though nanoparticles are not a group of similar substances. Nanoparticles tend to behave differently from larger particles of the same substance.

An important feature of nanoparticles is that they are small enough to go where bigger particles can't. Nanoparticles can get into human cells, where they can deliver medicines, be tracked by UV light, or be triggered to destroy cancer cells. They can also be used to lay down microscopic circuitry.

Even if we know that larger particles are safe, that doesn't mean that nanoparticles will be too.

We can't easily predict how nanoparticles might behave in the human body or the environment. We have to be careful to test them first.

A nanoparticle is simply a very small particle of matter with a diameter of one to 100 nanometers. One billion nanometers is equivalent to a meter. Nanoparticles can be made from many different substances. Some nanoparticles are safe, some are hazardous, and for many, we have yet to find out.

Nanoparticles have much higher surface-area-to-volume ratios than larger particles. This generally makes them react more quickly than larger particles and be better catalysts. Some nanoparticles interact with light in special ways, meaning we can get unique behavior from a material that seems very ordinary. And finally, some nanoparticles can go into places that larger particles simply cannot.

Please, watch the following video: https://www.youtube.com/watch?v=vvWx4KgOmGY

As a society, we need to be mindful about which nanoparticles we release, because some of them can do a lot of damage and build up in the ecosystem enough to kill plants and animals.

The application of nanomaterials in several areas of the biomedical field has shown remarkable progress and provided a lot of opportunities for the future of nanomedicine. Among these, polymeric and ceramic nanoparticle systems proved to be versatile nanocarriers and exhibit numerous biomedical applications. PNPs play an important role in the diagnosis and treatment of a wide range of diseases, for instance, viral infections, cancer, cardiovascular diseases to pulmonary and urinary tract infections. They not only carry the drug to the target site but also increase the efficacy of drugs in treating diseased tissue.

Please, watch the following video: https://www.youtube.com/watch?v=f7hMhL_N4k8

Similarly, ceramic nanoparticles also exhibit numerous applications in dentistry, orthopaedics, anticancer drug delivery, and tissue engineering. They offer advantages like good biocompatibility, biodegradability, osteoinductivity, resorbability, and hydrophilicity. The ease with which these nanoparticle systems can be prepared and implemented endorses their future development and success. Although multiple types of PNPs and CNPs are available in the market, further studies are yet to be done. Various issues associated with PNPs, like toxicity, immunogenicity, route of administration, dissociation of polymers, and their clearance, should be taken care of for the safety of patients. Understanding the potential biomedical applications of such systems will provide insight into their future developments.

We are discovering that when molecules and atoms assemble into particles between 1 and 100 nanometers in size, different laws dominate at that scale than in our everyday experience of objects. Unique properties begin to emerge for substances at the nanoscale, including unique optical, mechanical, electrical, and thermal properties.

Nanoscale particles maximize surface area and therefore maximize possible reactivity.

The smaller something is, the larger its surface area is compared to its volume. This high surface-to-volume ratio is an important characteristic of nanoparticles.

The large surface area to volume ratio of nanoparticles opens many possibilities for creating new materials and facilitating chemical processes. In conventional materials, most of the atoms are not at the surface; they form the bulk of the material. In nanomaterials, this bulk does not exist.

3. Nanoparticle substances

Nanoparticles are not a group of similar substances. Nanoparticles tend to behave differently from larger particles of the same substance. We expect substances like alkanes to exhibit similar chemical behaviour.

Let’s imagine we take a substance, and we turn it into a nanoparticle. When we compare it to another substance that we’ve also turned into a nanoparticle, the chemical properties of that little nanoparticle are going to be more like the larger particle of the same substance than a different type of nanoparticle.

A few things make nanoparticles special: they have much higher surface-area-to-volume ratios than larger particles, making them much more reactive.

Activity:

Let's imagine we've got a sugar cube that is one centimeter along each side; the volume of the cube is one centimeter multiplied by one centimeter multiplied by one centimeter multiplied by one centimeter; one centimeter cubed. A cube has six faces, and each face is one centimeter by one centimeter; the total surface area is six centimeters squared, a surface-area-to-volume ratio of six squared centimeters for each cubic centimeter. For exactly the same volume, the same amount of material, but broken into cubes that are 100 nanometers by 100 nanometers by 100 nanometers, using exactly the same amount of material.

It has the same volume, but each particle has much more exposed surface. The total surface area is 600000 centimeters squared, a surface area that's 100000 times bigger.

- Neglecting any other factors simply because they're so small, nanoparticles are likely to be more reactive, more flammable, and better catalysts. You can use less material to have the same surface area and the same catalytic activity.
- Visible light has a wavelength between 700 and 400 nanometers. When we shrink substances down to the nanoparticle size, some of them absorb light more, and some of them absorb light less. On the human scale, gold is shiny and, of course, golden. Golden nanoparticles interact with light in special ways and look red when suspended in solution, but meanwhile, titanium dioxide is a white pigment used in paints. Nanoparticles of titanium dioxide suspended in water or spread thinly in sunscreen are invisible to the human eye, but they still absorb hazardous ultraviolet radiation.

3.1 Metal and alloy nanoparticles

There are many types of nanoparticles, and some of them have very unusual structures. As particles get smaller, the atoms or ions don't fit together quite as well as they did when the particles were bigger. Particles of metal tend to keep the same structure as they get smaller.

- ✓ Let's look at a few metals at once: lithium, potassium, and caesium, three of the alkali metals. And let's have a look at how many atoms we'd expect to find in a particle that has a diameter of one nanometer, 10 nanometers, or 100 nanometers.

- ✓ In a one-nanometer lithium particle, we'd expect about 24 atoms, but a one-nanometer particle of cesium would only have five. A one-nanometer particle has a strict volume. We can fit fewer big atoms and more small atoms in the same volume. We can fit many more atoms into a larger particle.
- ✓ In a 10-nanometer lithium particle, we expect about 24000 atoms. And in a 10-nanometer cesium particle, we expect only 4600.
- ✓ When we increase the diameter by a factor of 10 to 100 nanometers with 24 million lithium atoms or 4600000 cesium atoms, these are estimates based on how we see metal atoms fit together at larger scales, but what we can see is that nanoparticles can have very few atoms, like five atoms in a one-nanometer cesium atom, or very many atoms, like 24 million lithium atoms in a 100-nanometer particle.

Scientists have determined that gold and silver nanoparticles can pass through mammalian and bacterial lipid membranes. Metal nanoparticles are now studied for drug delivery and antibacterial applications.

The metal nanoparticles can be optimized for drug-delivery purposes and to enter and break down bacterial cells. It is also thought that metal nanoparticles will be used to make microscopic electrical circuits because metal nanoparticles can conduct electricity.

- Many metallic nanoparticles also tend to have unusual colours and toughness values. Copper nanoparticles are surprisingly tough, and nanosized gold can have a red, orange, green, or blue colour.
- Different types of nanoparticles can be used to make films, wires, and fibers. One-dimensional nanowires are used in electronic circuits, and incredibly small nanofibers exist inside our water filters ensuring the water is safe to drink.

3.2 Magnetic nanoparticles

Materials are classified by their response to an externally applied magnetic field. Five basic types of magnetism can be described: diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetisms. All materials display this type of weak repulsion to a magnetic field known as diamagnetism.

Materials that retain permanent magnetization in the absence of an applied field are known as hard magnets. Materials having atomic magnetic moments of equal magnitude that are arranged in an antiparallel fashion display antiferromagnetism. The macroscopic behaviour is similar to ferromagnetism. Above the Néel temperature, the substance becomes paramagnetic.

Magnetization behaviour of ferromagnetic and superparamagnetic NPs under an external magnetic field:

Under an external magnetic field, domains of a ferromagnetic NP align with the applied field. The magnetic moment of single-domain superparamagnetic NPs aligns with the applied field. In the absence of an external field, ferromagnetic NPs will maintain a net magnetization, whereas superparamagnetic NPS will exhibit no net magnetization due to the rapid reversal of the magnetic moment.

Activity: Biomedical applications of magnetic nanoparticles

Size and surface functionality are two major factors in the in vivo use of these particles. Particles with diameters of 10 to 40 nm including ultra-small SPIOs are important for prolonged blood circulation; they can cross capillary walls and are often phagocytosed by macrophages which traffic to the lymph nodes and bone marrow.

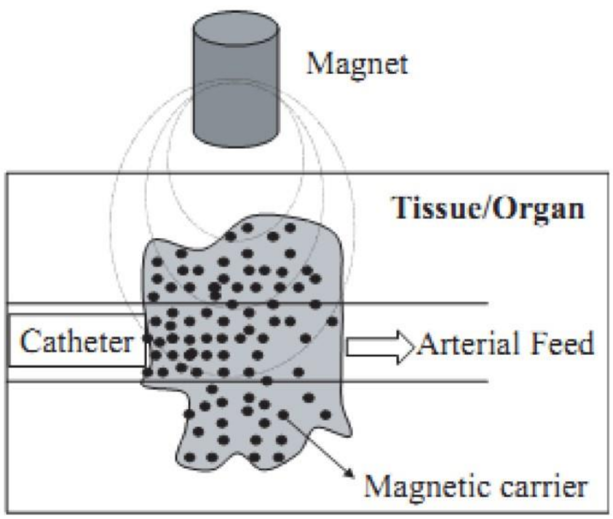

Figure 4. Nanoparticles

(Source: www.researchgate.net)

Nanotechnology is an emerging field that deals with the study, design, and application of materials with structural features having at least one dimension in the nanometer range (1–100 nm). The unique size-dependent properties of nanoparticles make them potential candidates for their applications in different areas, ranging from environmental science to an emerging multidisciplinary field that includes chemistry, physics, biology, and medicine. It is crucial to understand their nature at the cellular and biomolecular levels. The interaction of nanoparticles with biological macromolecules, such as protein and DNA, proved beneficial in therapeutic fields ranging from molecular diagnostics and biosensors to drug discovery, gene/protein delivery, and drug delivery.

Schematic representation of the magnetically driven transport of drugs to a specific region. A catheter is inserted into an arterial feed to the tumour, and a magnetic stand is positioned over the targeted site.

Nanoclusters are ultrafine particles of nanometer dimensions located between molecules and microscopic structures (micron size). Viewed as materials, they are so small that they exhibit characteristics that are not observed in larger structures (even 100 nm); viewed as molecules, they are so large that they provide access to realms of quantum behaviour that are not otherwise accessible. In this size, many recent advances have been made in biology, chemistry, and physics.

3.3 Polymer/ceramic nanoparticles

Literature is rich in reports illustrating the role of polymeric and ceramic nanoparticles in numerous diagnostic, pharmaceutical, and medical fields because of several associated properties such as good biocompatibility, easy design, chemical inertness, and high heat resistance.

Nanoceramics received significant attention in the recent past due to their unique processing, mechanical strength, toughness, bioactivity, and controllable crystallinity. They can be prepared easily with desired size, shape, and porosity. Among the varieties of nanomaterials, nanostructured ceramics (or nanoceramics) are used for applications in orthopaedic and dental treatments.

The different types of ceramic nanoparticles (CNPs) used are titania-based ceramics, alumina ceramics, calcium phosphate (CaP), tricalcium phosphate (TCP), hydroxyapatite (HAP), calcium sulfate and calcium carbonate, and bioactive glass ceramics. Among the areas of polymer and ceramics nanoparticle applications, the most explored one is the biomedical field.

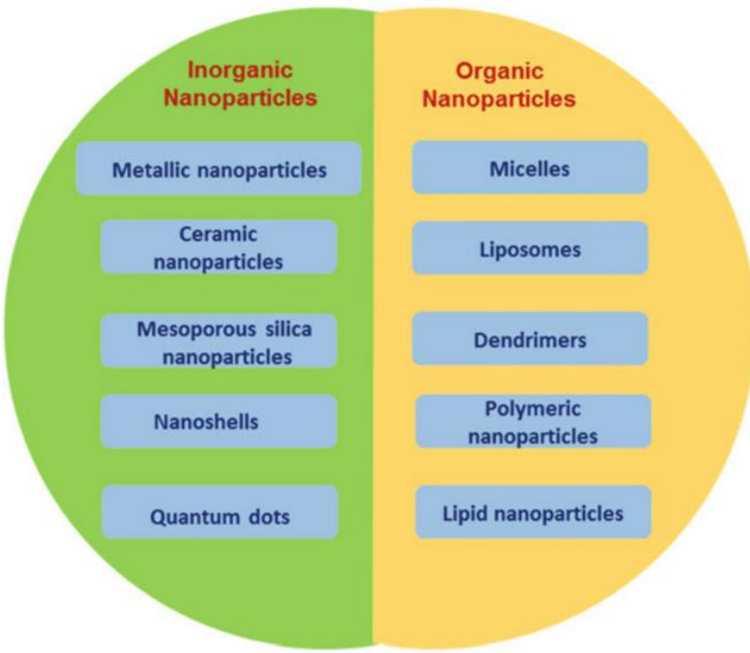

Figure 5. Types of Nanoparticles
(Source: www.researchgate.net)

- Nanomaterials which can be utilized for various biological and biomedical applications are termed nano-biomaterials.
- Polymers are macromolecular structures which are made up of a large number of monomer units which differ in composition, structures, functionalities, and properties. These variations in the properties and compositions of polymers are being used to generate polymer-based nanoparticles for biomedical applications.
- The use of polymeric nanoparticles is not only restricted to drug delivery but they are also used in biosensing and bioimaging and as a diagnostic tool in medicine.

For therapeutic applications, the drug, free or encumbered into nanoparticles, has to reach the target site, which can be at the cellular or molecular level. There are certain barriers encountered while delivering these nanoparticle systems.

Biocompatible ceramics, also known as bioceramics, consist of both macro- and nanomaterials and their development has hastened in the last few years. Bioceramics are mainly used for bone, teeth, and other medical applications. The inorganic material can be classified into ceramic and metallic nanoparticles.

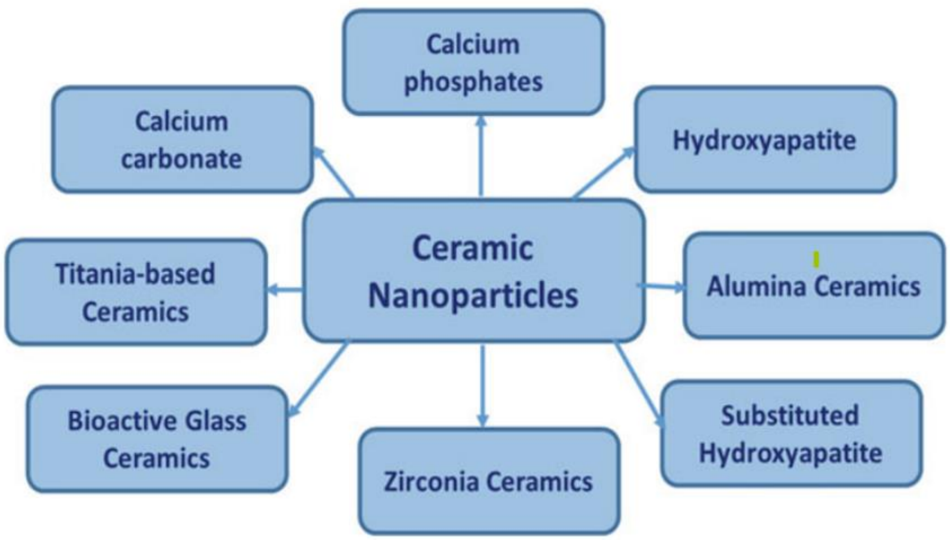

Figure 3. Types of widely used ceramic nanoparticles
(Source: www.researchgate.net)

Researchers have developed various methods for the preparation of nanoparticles for drug delivery depending on how to load the drug onto the nanoparticle. Understanding their potential biomedical applications at the molecular level will provide major insight into their future developments and can hold a promising future in numerous areas of health and medicine.

4. Case studies and success stories

The teacher's role will be to invite students to encourage students to express ideas, prior knowledge and questions about the topic while promoting interaction and communication between them. The teacher will invite students to explore the topic, to investigate information about the benefits of nanoscience.

The teacher should prepare activities to set up a debate and keep the audience engaged. Students will follow the teacher's presentation and will debate the case. Through this activity, participants will follow the case presentation, students will raise arguments, finding the advantages and disadvantages of learning about nanoparticles.

Activity 1

Comparing Medium-Sized Nanoparticles with a Single Strand of Human Hair

Human hair has a diameter of 80000 nanometers. How many nanoparticles with a diameter of 50 nanometers would fit across the human hair?

- *Human hair varies in thickness by quite a lot, but it's typically 100 micrometers wide, which is about 100000 nanometers. The particular hair we've been given is 80000 nanometers in diameter, which is just a little bit thinner.*
- *Nanoparticles are particles with a diameter of 1 to 100 nanometers, the nanoparticles we'll be using have a diameter of 50 nanometers. To figure out the number of nanoparticles we need, we simply have to take the diameter of the hair and divide it by the diameter of the nanoparticle.*
- *We plug in our values to get 80000 nanometers divided by 50 nanometers. The answer is 1600 nanoparticles.*

Activity 2

Because they're so small, nanoparticles are likely to be more reactive, more flammable, and better catalysts.

- ✓ Visible light has a wavelength between 700 and 400 nanometers. When we shrink substances down to the nanoparticle size, some of them absorb light more, and some of them absorb light less. On the human scale, gold is shiny and, of course, golden. But golden nanoparticles interact with light in special ways and look red when suspended in solution. But meanwhile, titanium dioxide is a white pigment used in paints. But nanoparticles of titanium dioxide suspended in water or spread thinly in sunscreen are invisible to the human eye, but they still absorb hazardous ultraviolet radiation.

Activity 3

Identifying the Advantages of affirmation: Nano-treating, by adding a low loading of ceramic nanoparticles into a metal matrix, can effectively reduce the hot cracking susceptibility of aluminium alloys during solidification processes such as casting, welding, and additive manufacturing**.**

Activity 4

Identifying the Advantages of affirmation:

Constantly developing nanotechnology provides the possibility of manufacturing nanostructured composites with a polymer matrix doped with ceramic nanoparticles, including ZnO.

The teacher will invite students to debate all aspects of the activities described, encouraging students to express ideas, prior knowledge, and questions about the topic, while promoting interaction and communication between them.

In the conclusion phase, the main points, answers, results, and steps are summarized. In this phase, students may have discussion, communication, and reflection to wrap up key topics addressed. Students are encouraged to express their views and their opinions.

5. References

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