NANOWARE Curriculum

MODULE 2: NANOMATERIALS

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NANOWARE

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DIGICULT

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Contents

1. Introduction to the Module

This module is about understanding the different types of nanomaterials. It introduces the learner to different syntheses and briefly explains nanomaterial characterizations. Finally, it presents several nanotechnology applications, thus highlighting their importance and promising potential in various fields.

Description

This module will introduce learners to the basic features of nanomaterials. To that end, it will cover the different types of nanomaterials, their synthesis, and the reasons they differentiate. Furthermore, it will cover various applications of nanomaterials and will present a few case studies.

Goals

With this module, learners will learn that there are different types of nanomaterials and that they are categorized concerning their synthesis, albeit naturally or artificially created. Learners will also understand that nanomaterials have multiple applications in various industries and that examples from common products showcase the importance and potential of such materials in human progress.

Learning Objectives

In this module, learners will become acquainted with nanoscience and nanotechnology through a comprehensive presentation of nanomaterials. In this way, they will become more aware of the importance of this field in everyday life and, subsequently, more confident in integrating nanomaterials and their applications into their school curricula.

Learning Outcomes

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

- Know how different nanomaterials are characterized
- Understand how nanomaterials are used in practice
- Differentiate the types of nanomaterials
- Analyze the synthesis of nanomaterials

Estimated seat time

The completion of the module along with the implementation of the knowledge provided will last 3 hours.

2. Nanomaterials

Nanoscience and nanotechnology observe and manipulate individual atoms and molecules. In this way, they have developed the ability to alter the properties of matter at the nanoscale and create new structures for a multitude of usages (NNI, 2022, NGS, 2022).

2.1 Types of nanomaterials

Nanomaterials

Nanomaterials can be defined as "***any organic, inorganic, or organometallic material that present chemical, physical, and/or electrical properties that change as a function of the size and shape of the material"*** (Hochella et al., 2019).

There are different types of nanomaterials, and different ways to classify them.

Natural nanomaterials

These materials **occur naturally.** This means that they exist in the world "through (bio)geochemical or mechanical processes, without direct or indirect connection to a human activity or anthropogenic process" (Hochella et al., 2019).

Examples:

- Volcanic ash particles
- Smoke particles
- Hemoglobin (Hb/ molecules in our blood)
- The nanoscale structures that make up the colours on peacocks' feathers (the structures' spacing on the feathers' surface result in the brilliantly colourful effect)

Exploring Natural Nanomaterials

https://www.youtube.com/watch?v=aJCA0yGRrCI

Image title: Peacock feathers Source: Pixabay.com

Artificial nanomaterials

Artificial nanomaterials are those that occur because of human activity. This means that they were created unintentionally, as a result of objects or processes created by people.

Examples:

- Exhaust from fossil fuel burning engines
- Some forms of pollution

Incidental nanomaterials

Some of the artificial nanomaterials are **incidental**. For instance, exhaust nanoparticles are produced by vehicle engines, without an initial intent to be produced as nanomaterials (NGS, 2022).

Therefore, nanomaterials can be defined as incidental when they are "*unintentionally produced as a result of any form of direct or indirect human influence or anthropogenic process*" (Hochella et al., 2019).

! Another example of incidental nanomaterials is welding fumes containing nanoparticles.

Image title: Welder

Source: Pixabay.com

Intentionally produced/engineered nanomaterials.

While some nanomaterials are produced unintentionally, others are developed intentionally by scientists and engineers to be used in various industries, from manufacturing to medicine.

These are called **intentionally produced** or **engineered** nanomaterials.

Anthropogenic nanomaterials.

Anthropogenic nanomaterials include both **incidental** and **intentionally produced/ engineered** nanomaterials, all of which are the result of direct or indirect human influence.

Image title: Power station

Source: Pixabay.com

2.2 Synthesis & Characterization of nanomaterials

Fullerenes and Nanoparticles

"*One way to classify nanomaterials is between fullerenes and nanoparticles. This classification includes both naturally occurring and man-made nanomaterials*" (NGS, 2022).

Fullerenes

Fullerenes are **allotropes of carbon**.

! A chemical element can exist in different molecular forms. These are called allotropes.

Examples of carbon allotropes:

- Diamonds
- Graphite

Fullerenes are spherical or tubular molecular structures consisting of carbon atoms thickly arranged and strongly bonded.

Buckyballs

Buckyball is the nickname for *buckminsterfullerene* (C_{60}): a type of **spherical fullerene**. Buckyballs are "nanometer-sized carbon molecules shaped like soccer balls—tightly bonded hexagons and pentagons" (NGS, 2022).

Buckyballs are very resilient because they are very stable. As a result, they remain unchanged in extreme conditions like extreme temperatures, extreme pressure, and even extreme environments like outer space.

"Buckyballs are the largest molecules ever discovered in space, detected around planetary nebula in 2010" (ibid.).

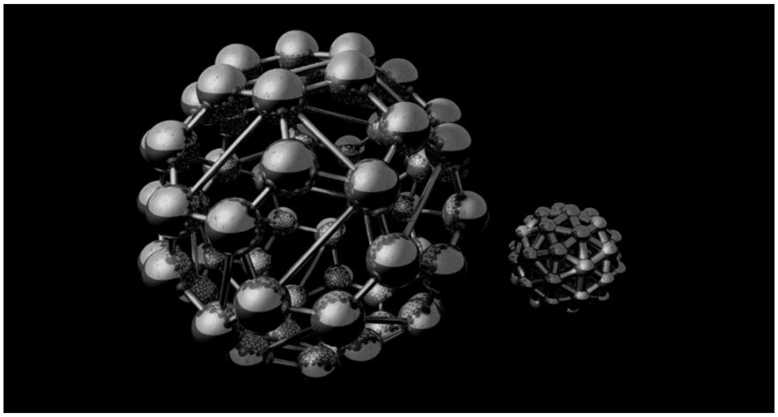

Image title: Buckyball
Source: Pixabay.com

Buckyballs are structured like spherical, solid cages, in which any atom or molecule remains safe and unaltered.

This cage-like and protective structure is attractive to scientists looking to safely encase atoms to transfer them within systems: this is the case with *Helium-impregnated buckyballs* that can be used as *chemical tracers* tracking pollutants in rivers etc. (Folger, 2019).

Nanotubes

Nanotubes are **tubular fullerenes** (NGS, 2022).

Carbon nanotubes have remarkable properties (chemical, electronic, mechanical, and optical) and are very resilient, strong, and flexible. This is the result of how carbon atoms bond with each other.

! *Carbon nanotubes are harder than diamonds and more flexible than rubber (ibid)*.

Carbon nanotubes are extremely popular in many scientific and technological fields thanks to their remarkable properties.

Examples:

- Environmental and health sciences use carbon nanotubes in chemical sensors (ScienceDirect, 2022).
- NASA is experimenting with carbon nanotubes to produce "blacker than black" coloration on satellites to reduce reflection and optimize data collection (NGS, 2022).

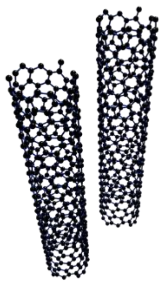

Image title: Carbon nanotubes

Source: Pixabay.com

Nanoparticles

Nanoparticles are small particles that range between 1-100 nanometres in size.

There are different groups of nanoparticles:

- Fullerenes
- Metal nanoparticles
- Ceramic nanoparticles
- Polymeric nanoparticles

Nanoparticles have high surface area and nanoscale size, which offers them unique physical and chemical properties; as a result, they are highly attractive to various industries and applications (Khan et al., 2019).

Intentionally Produced Nanomaterials

There are four main types of intentionally produced nanomaterials:

- carbon-based
- metal-based
- dendrimers
- nanocomposites

1. Carbon-based nanomaterials

Carbon-based nanomaterials are intentionally produced and can include:

- Fullerenes
- Carbon nanotubes
- Graphene and its derivatives
- Graphene oxide
- Nanodiamonds
- Carbon-based quantum dots (Patel et al., 2018).

2. Metal-based nanomaterials

There are different types of metal-based nanomaterials. These include -but are not limited to:

- Gold
- Silver
- Copper
- Iron
- Zinc
- Platinum (Yaqoob et al., 2020).

3. Dendrimers

Dendrimers are complex, treelike nanoparticles built from *linked, branched units* that compose extremely strong structures (NGS, 2022).

Dendrimers consist of an inner core and a peripheral shell that expands in abundant terminal groups (ScienceDirect, 2022b).

The dendrimer branching is called “dendrimer generation” (ibid.).

Each part of a dendrimer can be designed to perform a specific chemical function.

Dendrimers are highly attractive to biomedical applications, as they can fulfil multiple functions.

Example: A single dendrimer can *deliver a drug to a specific cell*, and also *trace that drug's impact on the surrounding tissue* (NGS, 2020).

4. Nanocomposites

Nanocomposites are hybrid materials that combine two or more materials, at least one of which is a nanomaterial.

Types of nanocomposites :

- Nanoceramic matrix composites (NCMCs)
- Often called “nano clays,” they are used in applications like package coating to increase materials’ strength and resilience.
- Metal matrix composites (MMCs)
- Stronger and lighter than bulk metals, they are ideal for such applications as, for instance, making lighter vehicles.
- Polymer matrix composites (PMCs)

Often used to create industrial plastics and popular in nanomedicine for tissue scaffolding. (NGS, 2022).

Please, watch the following video:

The Mighty Power of Nanomaterials: Crash Course Engineering #23

https://www.youtube.com/watch?v=IkYimZBzguw

2.3 Applications of the use of nanomaterials

Nanomanufacturing

Nanomaterials can be synthesized in two ways:

- **top-down** approach
- **bottom-up** approach

Top-down nanomanufacturing is about manipulating *bulk materials* to create *fine particles in nano dimensions* (Parmasimav et al., 2021). An example of this approach is the creation of graphene-based microchips (as opposed to silicon-based ones) – a revolutionary product with great potential.

Bottom-up nanomanufacturing is about assembling fine particles to create nanomaterials through self-assembly or co-precipitation methods (ibid.). An example of this approach is the creation of nano-sized electronic devices using single atoms and molecules (e.g., microchips).

Nanotechnology and the Environment

Nanotechnology is used by researchers to create ***affordable, high-tech, and energy-efficient*** products like light bulbs, paints, computer screens, and fuels producing lower emissions.

Nanotechnology is also used to improve ***alternative energy source applications***. For instance, scientists are now experimenting with print-like or even solar panels to increase efficiency and ensure easy and low-cost instalment.(NGS, 2022)

In **water**, nanomaterials can reduce toxicity by eliminating toxic metals and organic molecules (e.g., dangerous chemicals, virus cells, etc.).

Nanotechnology is also used to reduce ***oil spill*** pollution by utilizing nanoparticles' magnetic properties.

Consumer products

Scientists and engineers are using nanotechnology in a variety of consumer products.

Examples:

Clothing (e.g., coating methods to make fabric water-repellent or more stain-resistant)

Cosmetics (e.g., products with enhanced clarity, better absorption, better UV protection, etc.)

Athletics (e.g., nano-additives to make sports equipment lighter and more resilient).

Packaging and surface protection materials (stronger, more resilient, and lightweight solutions)

Food enhancers (to improve texture and flavours)

Electronics (to create faster portable and more efficient systems that can manage and store larger amounts of data and that can consume less power).

Nanomedicine (procedures/disease treatments, medical devices/tools etc).

- Nanomaterials can be used to reduce bleeding and speed coagulation.
- Nanoparticles can be incorporated into bandages to trap microbes and enhance tissue regeneration.
- Nanoparticles can deliver medications to specific cells to prevent healthy tissue from being damaged when not necessary (e.g., in cancer treatments).
- Dendrimers can increase speed and efficiency in drug delivery.
- Fullerenes can be manipulated to have anti-inflammatory properties to slow or even stop allergic reactions.
- Nanoparticles can be manipulated to detect and attach themselves to specific proteins or diseased cells. This improves diagnostic procedures (testing and imaging).

Please, watch the following video:

Nanotechnology is not simply about making things smaller | Noushin Nasiri |TEDxMacquarieUniversity

https://www.youtube.com/watch?v=M8d3pxVb4c4

3. Case studies and success stories

Air0 – Breathe Finland

https://air0.fi/en/

The company uses nanotechnology to perfect mechanical and electrical air purification.

Its product smAIRt®600 removes even the finest particles that can transmit airborne diseases or otherwise deteriorate indoor air, thanks to nanomaterials: it can remove volatile organic compounds, mold, bacteria, viruses, smoke, smells, etc., without producing any ozone.

CNM Technologies, Germany

https://www.cnm-technologies.com

The company specializes in developing, producing and marketing carbon-based nanomembranes. These molecular-thin membranes are *the thinnest polymer films in the world*, according to their manufacturer. They can be used in various fields, including medicine, energy, and electronics.

Nanoalps GmbH, Italy: Nanoalps® System SOIL

http://www.nanoalps.com/en/

The company uses nanotechnology in applied geotechnics and development. Its product Nanoalps® System SOIL can be used to decontaminate soil and immobilize harmful substances in combination with hydraulic binders. It can also be used to consolidate, stabilize, and toughen roadways, courses and grounds.

4. References

ScienceDirect (b). (2022). *Dendrimer - an overview*. ScienceDirect Topics. Retrieved October 9, 2022, from https://www.sciencedirect.com/topics/nursing-and-health-professions/dendrimer

ScienceDirect. (2022). *Carbon nanotubes- an overview*. ScienceDirect Topics. Retrieved October 9, 2022, from https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/carbon-nanotubes

Folger, T. (2019, November 12). *Cages of Carbon*. Discover Magazine. Retrieved October 9, 2022, from https://www.discovermagazine.com/the-sciences/cages-of-carbon

Hochella, M. F., Mogk, D. W., Ranville, J., Allen, I. C., Luther, G. W., Marr, L. C., McGrail, B. P., Murayama, M., Qafoku, N. P., Rosso, K. M., Sahai, N., Schroeder, P. A., Vikesland, P., Westerhoff, P., & Yang, Y. (2019). Natural, incidental, and engineered nanomaterials and their impacts on the Earth System. *Science*, *363*(6434). https://doi.org/10.1126/science.aau8299

Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, applications and toxicities. *Arabian Journal of Chemistry*, *12*(7), 908–931. https://doi.org/10.1016/j.arabjc.2017.05.011

nanoHUB. (2009). *A Comparison of Scale: Macro, Micro, Nano*. nanoHUB.org. Retrieved October 10, 2022, from https://nanohub.org/resources/26670/download/Comparison_of_scale_Presentation.pdf

NNI (b). (2022). *Applications of nanotechnology*. National Nanotechnology Initiative. Retrieved October 10, 2022, from https://www.nano.gov/about-nanotechnology/applications-nanotechnology

Patel, K. D., Singh, R. K., & Kim, H.-W. (2018, December 21). *Carbon-based nanomaterials as an emerging platform for Theranostics*. Materials Horizons. Retrieved October 9, 2022, from https://pubs.rsc.org/en/content/articlelanding/2019/mh/c8mh00966j

Yaqoob, A. A., Ahmad, H., Parveen, T., Ahmad, A., Oves, M., Ismail, I. M. I., Qari, H. A., Umar, K., & Mohamad Ibrahim, M. N. (2020). *Recent advances in metal decorated nanomaterials and their various biological applications: A Review*. Frontiers. Retrieved October 9, 2022, from https://www.frontiersin.org/articles/10.3389/fchem.2020.00341/full