NanoDialogue
of the German Government

Opportunities and risks of active materials at the nano scale

An introduction for interested parties

Report

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1 Introduction

This report is aimed at people who want to know what opportunities and risks the use of active, nanoscale materials could pose. First, it describes what is meant by active, nanoscale materials in this report. Then, various examples of possible fields of application of these materials are presented and the possible (future) benefits of active, nanoscale materials are discussed in comparison to conventional materials and technologies. In addition, information on known possible risks is presented. In Chapter 4 the legal requirements for these materials are described.

Research on active, nanoscale materials is extremely diverse. This is partly due to the fact that many different materials and functionalities are grouped together under this heading. These, in turn, can be used in many different application areas and products. Since active, nanoscale materials have the potential to enable significant technological advances, the field is very attractive for researchers and is characterised by a high level of dynamism. Due to this diversity and dynamism, this report can neither be comprehensive nor reflect the current state of research and development in detail. Instead, it is intended to provide a general insight into the research field.

This report is based on the presentations and discussions of a two-day stakeholder dialogue in which representatives from authorities, science and civil society organisations discussed the opportunities and risks of active, nanoscale materials. The ExpertDialogue “Opportunities and risks of active materials at the nano scale” was organised by the Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection as part of the Federal Government's NanoDialogue in June 2022. Documentation of this event is available in German and English on the Ministry’s Website.

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUV) launched the NanoDialogue with the establishment of the NanoCommission in 2006. When the use of nanomaterials and nanotechnologies was steadily increasing, relatively little was (yet) known about possible risks to humans and the environment, and regulation was not adapted to the special features of nanomaterials and nanotechnologies. The aim of the NanoCommission was to accompany the introduction of this technology through a continuous dialogue of stakeholders from industry, authorities, science and civil society organisations and to develop principles for the responsible use of nanomaterials. The NanoCommission concluded its work in 2010. Since 2011, the NanoDialogue has been continued in the form of two-day expert workshops. Reports of the NanoCommission, summaries of the expert dialogues and reports on the topics of the expert dialogues are available on the BMUV website.

2 What are active, nanoscale materials?

2.1 The nano scale

In this report, materials are referred to as active, nanoscale materials that are **smaller than 1000 nanometres** (nm) in at least one **dimension** (length, height, width). A “material” can consist of:

- a single substance (elements), e.g. aluminium or graphene
- compounds of several single substances, e.g. titanium dioxide or
- a mixture of individual substances and compounds, e.g. plastic

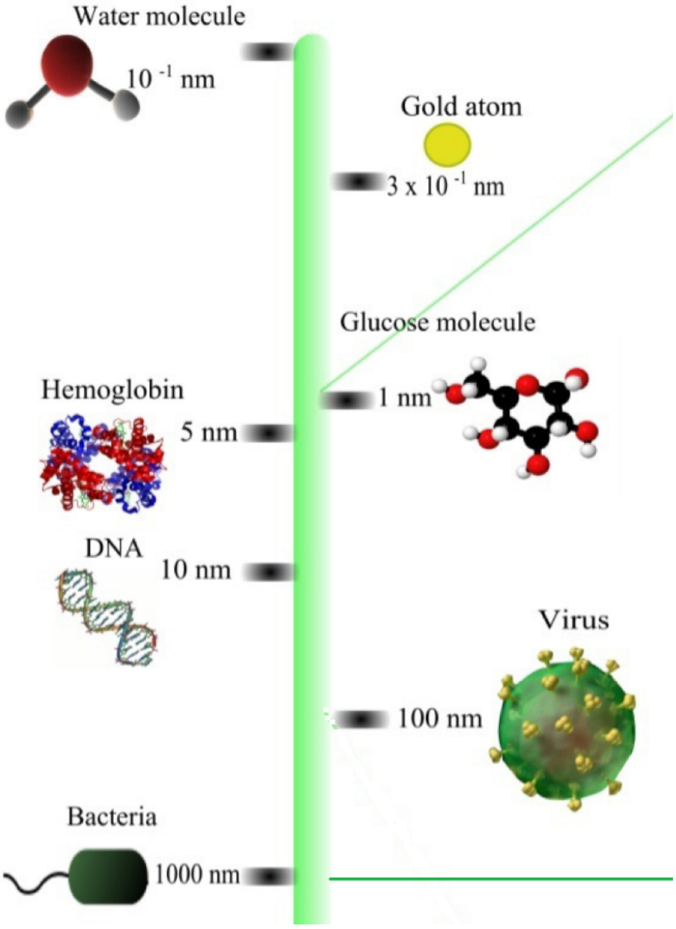

Figure 1: Comparison of nanometre sizes; Source: Wikimedia (creative commons) https://www.mdpi.com/1422-0067/15/5/7158, modified by Ökopol

A nanometre is as long as a billionth of a metre. In other words, 1000 nm are equal to 1 micrometre. In **Fehler! Verweisquelle konnte nicht gefunden werden.** the sizes of some objects in different size ranges are compared. The thin green lines mark the nanoscale range.

Nanoscale materials can have different properties than the larger forms of the same materials (“nanoeffects”). For example, the colour of gold particles differs in different nanosizes. The large surface area of nanoscale materials in relation to their volume can lead to higher reactivity or changes in other properties of the materials, such as the water solubility. Nanoscale materials can be flexible, while their “large” forms are rigid (e.g. nanoceramics).

The EU Commission defines in its recommendation that a “nanomaterial” consists of particles that are present independently or in so-called aggregates or agglomerates[1], where the size of more than 50 % of the particles is in a dimension between 1 nm and 100 nm[2]. Nanomaterials are thus a subset of nanoscale materials. A legal definition must be unambiguous, while from a scientific point of view other dimensions could also form the boundary to a nanomaterial, since “nanoeffects” can also occur with larger particles.

This report presents different materials at the nano scale. Some of them also meet the EU definition of a nanomaterial.

2.2 Activity

In this report, “active” materials are understood to be materials[3] that consist of nanoscale “building blocks” (individual substances and/or compounds) and react to external stimuli by absorbing, converting and/or releasing energy. During this activity, the energy level, the arrangement or the structure of the active, nanoscale material changes.

The external conditions that trigger an activity can be divided into chemical and physical stimuli. Chemical stimuli include, for example, metal molecules, biological molecules (proteins, enzymes) or organic solvents. Physical stimuli include light, electricity, magnetic fields or temperature. The presence or absence of the external environmental condition that triggers an activity can control whether an active, nanoscale material performs its function or not (switch for activity).

The following figures show schematically which types of activity or mechanisms can occur. On the left side of the figures are the stimuli acting on a material; the active, nanoscale material is in “State 1” (grey). Then the activity begins, in which energy is absorbed and/or converted either from the stimulus or from other sources in the environment. The material takes on the 2nd state (purple, right part of the figures). For some materials, there is no return to State 1.

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[1] Since nanoparticles are often very reactive, they tend to cluster. If the connection between the particles is strong, we speak of aggregates; if the particles are more loosely connected, we speak of agglomerates.

[2] For rod-shaped and plate-shaped particles, there are further conditions or exceptions in this definition.

[3] This description is based on the proposal for a definition of nanomaterials of the so-called "2nd generation" from a study for the European Observatory on Nanomaterials: Camboni et al. (2019): A state of play study of the market for so-called "next generation" nanomaterials. Helsinki. https://op.europa.eu/de/publication-detail/-/publication/1b84728b-f6e1-11e9-8c1f-01aa75ed71a1/language-en

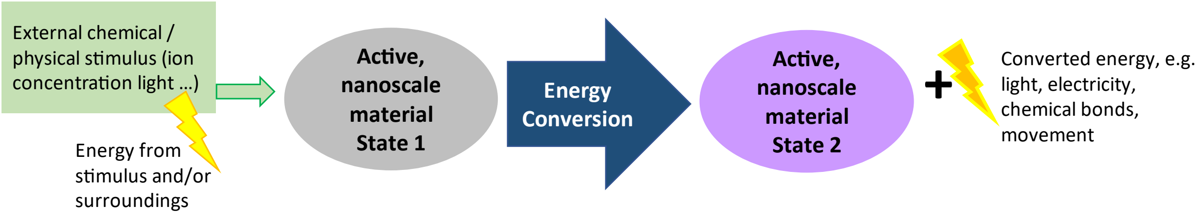

Figure 2: Activity of nanoscale materials: Case 1: no return to the initial state. Example: Nanocarrier delivering an active substance. Source: Own illustration

Other materials do not “consume” themselves during and because of their activity, but can return to the first state; this can happen without further stimulus (energy), triggered by the release of previously absorbed energy (Case 2, Figure 3) or upon a new stimulus (Case 3, Figure 4).

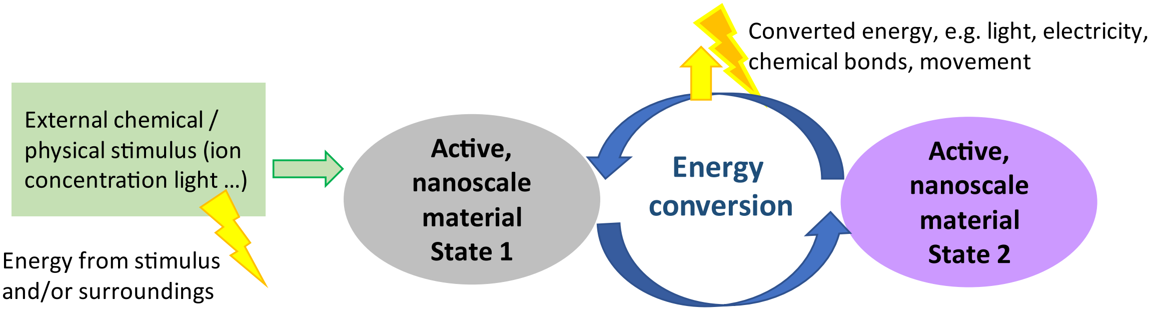

Figure 3: Activity of nanoscale materials: Case 2: Return to initial state through energy release. Example quantum dots. Source: Own illustration

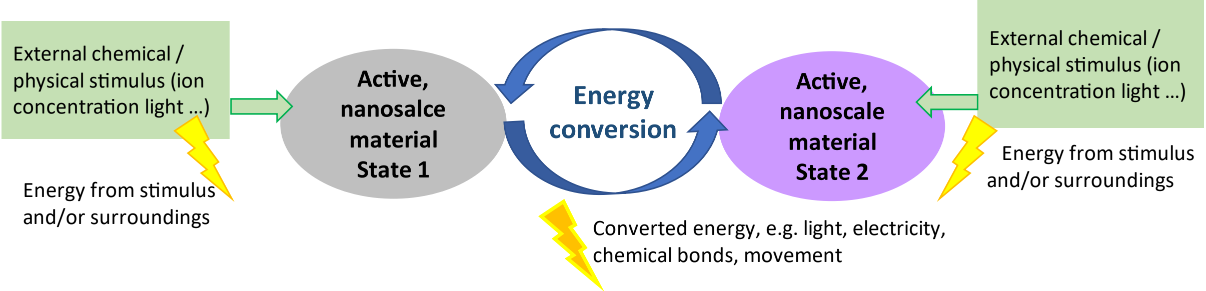

Figure 4: Activity of nanoscale materials: Case 3: Return to the initial state by further stimulus/energy or termination of the stimulus. Example: artificial muscles. Source: Own illustration

3 Examples of applications of active, nanoscale materials

As the many different active, nanoscale materials with different functions cannot all be described here, the following sections provide examples of different activities and applications. These include information on potential benefits and risks that may be associated with the materials and/or the respective application. Some materials are already on the market in products, while others are still being researched or developed.

3.1 Nanocarrier - transport of active substances

Nanocarriers are, in the broadest sense, “packaging” for (drug) substances or mixtures. They can resemble “transport boxes” that enclose an active ingredient or a scaffold to which an active ingredient can be attached. Once the nanocarriers arrive at their destination, they open or change their structure in response to an external stimulus and release the drug (targeted delivery). Figure 5 shows a type of nanocarrier called “liposome” because the outer shell consists of a lipid layer.

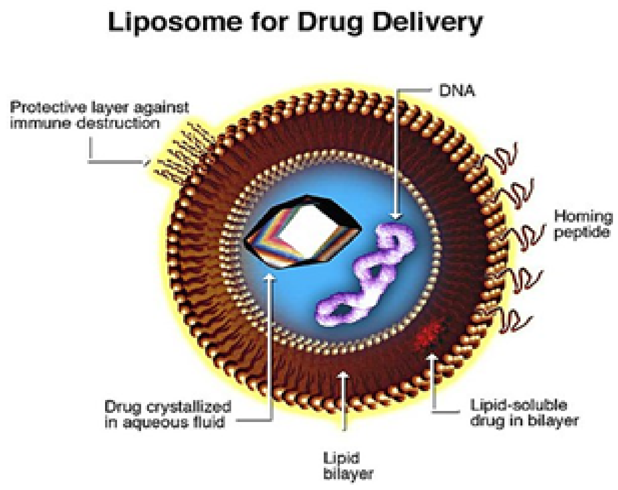

Figure 5: Structure of a liposome for drug transport. Source: Wikimedia (creative commons) https://commons.wikimedia.org/wiki/File:Liposome.jpg

Possible components of a liposomal nanocarrier

The protective layer on the outside prevents destruction of the carrier by the immune system.

The active substance is stored in the aqueous phase within the carrier (drug crystallised in aqueous fluid).

Lipid bilayer: Double layer of fat molecules

A lipid-soluble drug is stored in the bilayer.

Homing peptides are receptor proteins on the liposome’s outside that bind to tumour cells, for example, and are intended to “hold” the carrier at its site of action and attract it.

DNA is genetic information for an active substance that is produced by the body.

The activity of nanocarriers consists of a structural change that leads to the disintegration of the carrier and thus to the release of the active substance. This activity can be triggered by various stimuli, e.g. changes in pH, binding of the receptor proteins or enzymes. After the active ingredient is released, the carrier remains “empty and cannot be used again.

Nanocarriers can fulfil different functions (simultaneously), in particular:

- Packaging of the active ingredient to protect the active ingredient so that it does not break down or degrade in the body before it can take effect.
- Targeted delivery of active substances: Nanocarriers do not move actively, but blood transports them, including past their target cells (in particular in the liver). When the receptors of the nanocarrier come into contact with the target cells, they bind to them and the nanocarrier (and the active substance) accumulates in the tissue.
- Delivery into the cell: Targeted delivery of the active ingredient can also involve a nanocarrier passing a drug through a cell membrane. Nanocarriers can accomplish this membrane crossing in different ways.
- Dosage of the active ingredient: Depending on the nanocarrier and the activating stimulus, it is possible to control when and how quickly an active ingredient is released.

Benefits

Nanocarriers can increase the efficiency with which a (pharmaceutical) active ingredient reaches its target site in the body (availability). This can reduce the amount of medicines administered. As a result, the environmental input of drugs that are not absorbed by the body but excreted is also reduced. In addition, the lower dosage may mean that undesirable side effects occur less frequently or are less severe. If medicines have to be taken less often, this can also contribute to patients taking them more willingly (increased compliance).

Since nanocarriers protect against degradation, they enable the use of entirely new active substances that would be destroyed without “packaging” before they could develop their effect. A well-known example of this is the mRNA[4] vaccines against the coronavirus.

Nanocarriers are also used, in biocidal products, plant protection products and cosmetics for example. In cosmetic products, the nanocarriers also act in or on the human body. On the other hand, the target sites of biocidal products and plant protection products are animals, bacteria and fungi, as well as plants and algae. These products are often applied in an “environmentally benign” manner, i.e. the nanocarriers are released directly into the environment. The way nanocarriers function in these products does not differ from those in medicines.

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[4] Messenger RNA are chemical molecules that transcribe the blueprints for proteins from DNA and transport them to the places in the cell where the proteins are assembled. They are subject to constant assembly and disassembly in the cell.

Risks

Due to the increasing manufacture and use of nanocarriers in various products, the probability of people coming into contact with them is fundamentally increased. Similarly, increasing inputs of nanocarriers into the environment are to be expected, especially through biocidal products and pesticides. This leads to a general increase of human and environmental exposures.

Little is currently known about the possible environmental and health risks of using nanocarriers in medicine[5] and other products. In medicine, liposomes in particular are used as nanocarriers. Their building blocks (usually fats, proteins and DNA) are found in all living organisms. Therefore, it is assumed that the (components of the) nanocarriers are degraded by natural mechanisms. However, it is not yet sufficiently known whether this fully applies to all forms of liposomal nanocarriers or whether certain structures are not accessible to degradation.

In general, nanocarriers can consist of a whole range of different substances or structures, such as natural and artificial polymers, proteins, viruses, but also inorganic structures like silicon dioxide or metals such as gold, silver or iron. The question of their stability in the environment is a central aspect of risk assessment. If they are biodegradable or resemble naturally occurring substances, a rather low risk can be assumed.

3.2 Quantum Dots - Conversion of light

Quantum dots are 1 to 10 nm large particles that are mostly made of semiconductor materials, e.g. silicon or cadmium selenide. They can consist of several layers (like an “onion” of core and shells). Their special and influenceable optical and electronic properties arise from quantum effects that occur at the nano scale but not with larger forms of the materials.

Quantum dots absorb energy and emit it again in a modified form. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the mechanism for generating light of a specific colour, e.g. for displays: An external source of light acts as stimulus and excites the electrons in the semiconductor material of the quantum dot. Due to quantum effects, the absorbed energy can only be emitted in certain “portions”, i.e. a certain wavelength (here: light colour).

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[5] Medicines must be approved before they can be marketed. The benefits and risks of the medicines are reviewed as part of the trials. Therefore, it can be assumed that for nanocarriers, the benefits exceed the possible risks in any case for the drugs on the market.

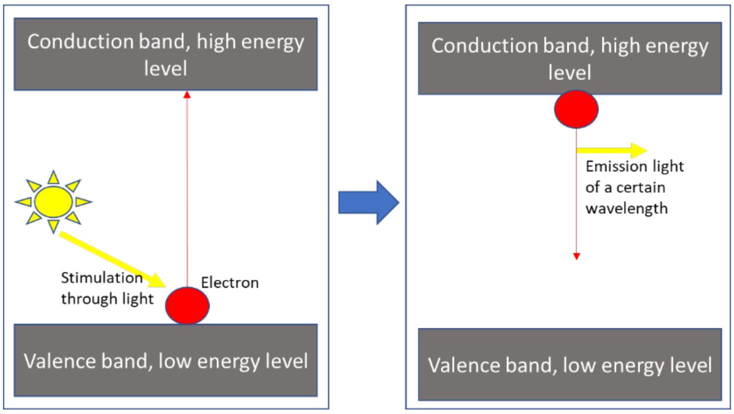

Figure 6: Simplified representation of the activity of quantum dots
Source: Own illustration

The wavelength of the energy emitted by a quantum dot is determined on the one hand by the type of semiconductor material. On the other hand - and this is the special thing about quantum dots - it depends only on the particle size of a particular material. This means, for example, that a particularly small semiconductor quantum dot produces blue light, while larger particles of the same material produce green or red light. If quantum dots are excited by light, the wavelength of the emitted light is usually larger, i.e. shifted towards the red region of the spectrum, than that of the exciting light. The intensity of the radiated energy (e.g. the brightness of light) depends on the surface of the quantum dot. Quantum dots can also emit energy in the infrared or UV range. The transition of electrons as charge carriers to a high energy level in the quantum dot can also be used in other ways, e.g. to generate electricity in solar cells or in electronic components (transistors).

Benefits

The special properties of quantum dots, such as their narrow-band emission, their insensitivity to oxygen, light, heat and water, as well as the possibility of precisely determining or shaping the properties of the particles through targeted syntheses, make them interesting for many areas of application. For example, they are already used in displays as “Quantum Dot Light Emitting Diodes (QLEDs)”. They are more brilliant and longer-lasting than organic LEDs (OLEDs), which have often been used up to now. However, many possible applications are still in the development stage, e.g. their use in the conversion of light in photovoltaics to increase the efficiency of solar cells, their use as luminescent materials or in so-called quantum computers.

Quantum dots can achieve both an increase in the efficiency of technological applications and an increase in quality (better imaging, higher resolution, use of new wavelengths, etc.) in many areas.

Risks

Some of the semiconductor materials used for quantum dots have toxic properties, e.g. gallium arsenide is classified as carcinogenic and toxic for reproduction. Some heavy metal compounds, e.g. those containing cadmium, are subject to legal restrictions[6] and are therefore increasingly being replaced by other, less toxic materials.

Figure 7: Waste electrical equipment that may contain rare and/or toxic materials
Source: Pixabay.com

Damage from (eco-)toxic materials is only possible if humans and/or the environment come into direct contact with them. In the case of quantum dots, this is only possible at workplaces (laboratory, production, etc.) where the materials occur as single material / particle, i.e. not bound in a matrix or product. In these processes, environmental emissions (exhaust air, waste water, waste) can also occur. While using a product, e.g. a display, direct contact with the quantum dots is normally not possible, as these are bound within the device and cannot escape. However, when electronic products become waste, quantum dots could be emitted from the waste treatment processes, resulting in potential exposure of workers and the environment.

There is a lack of reliable information about the behaviour of quantum dots. It is assumed that they are both mobile and stable in the body and could accumulate in certain regions/organs. It is also expected that at least the core of quantum dots is stable in the environment, while its outer shell (coating) is likely to degrade.

Overall, little is known about possible environmental and health risks.

Another challenge of using quantum dots in electronic devices is that the materials can hardly be recovered. Although electrical and electronic devices are at least partially collected separately at the end of their service life, there is a lack of technical equipment and processes to specifically recover the contained materials, which are

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[6] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Available at: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32011L0065

only present in very small proportions. Since some of the semiconductor materials of quantum dots are very rare, such “dissipative losses” should be taken into account when weighing up for or against the use of quantum dots in a particular application. For the element indium used in quantum dots, it is estimated that the known deposits worldwide will be used up in about 20 years[7].

3.3 Electroactive polymers - artificial muscles

Electroactive polymers are nanoscale materials whose dimensions change when a voltage is applied, i.e. they can lengthen and shorten or thicken and taper. This is why they are also called artificial muscles. The mechanical change of the polymers (activity) is stimulated by an electrical voltage (stimulus). Figure 8 schematically shows the structure and function of a gripper consisting of electroactive polymers.

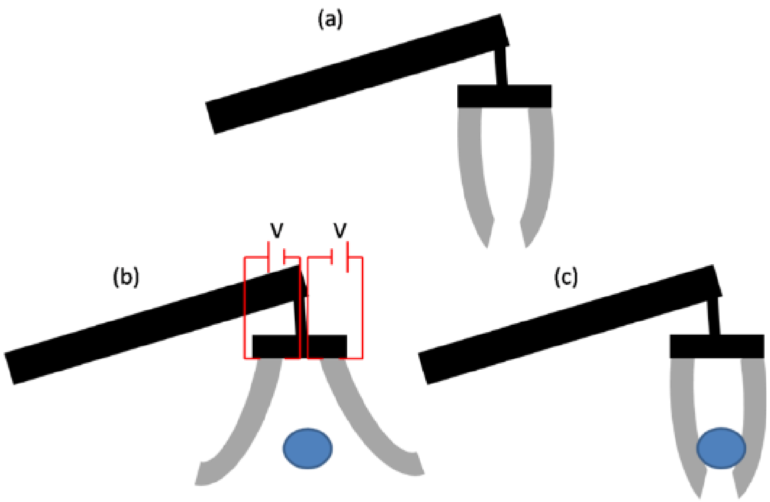

Figure 8: a) Gripping tool, b) Electrical voltage causes the fingers to open, c)Without voltage, the fingers return to their original position.
Source: Wikimedia https://commons.wikimedia.org/wiki/File:EAP-example2.png

Research is being conducted on different types of artificial muscles whose basic components are chains of carbon compounds (polymers) to which other compounds or substances can be attached that influence functionality.

The mechanism of how the movement is achieved can differ depending on the polymer and the overall structure of the artificial muscle.

Benefits

Research is still a long way from the use of artificial muscles in the human body. Possible future applications could be retinal implants or artificial organs produced by additive manufacturing technologies (3D printing), for example.

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[7] https://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/indium

Artificial muscles are already being used in medical products, however. For example, they are used as pumps that allow a very precise dosage of medication. Dressing materials and filter papers containing artificial muscles are being tested. In the next few years, the development of contractible medical sutures and the use of artificial muscles in endoscopy or surgical instruments can be expected.

Outside of medicine, artificial muscles are used in robotics. Here they replace conventional grippers and allow humans and machines to work closer together, as the risk of injury is significantly reduced with the “soft muscles” in contrast to the “hard, metallic” robot parts.

In a reverse functionality, i.e. when mechanical energy (deformation) is converted into electrical impulses, artificial muscles can also be used as pressure sensors.

Risks

At present, not much is known about the toxicity of the electroactive polymers, but it can be assumed that some of them are hazardous to the environment or health. If artificial muscles are used in or on the human body, defence reactions of the immune system are conceivable. A high stability of the electroactive polymers in living systems is assumed, which indicates a potential for low interaction (and thus damage) of the environment. However, the high stability desired for functionality could turn out to be problematic if no degradation of the polymers takes place in the environment (persistence).

In addition to the possible environmental and health risks of the use of electroactive polymers, there are also ethical questions in the context of so-called “human enhancement”, i.e. the “improvement” or “further development” of the human body, which concern the possible applications of artificial muscles.

3.4 Further examples of active, nanoscale materials

3.4.1 Photoactive, nanoscale materials

The use of light as a stimulus and energy source for nanoscale materials has already been described in connection with quantum dots (see Chapter 3.2). Another mechanism is two-tiered and enables or accelerates chemical reactions (catalysis). Photoactive materials absorb the energy of light, which changes their structure in such a way that they become very reactive, i.e. they “want” to react with a (certain) other chemical compound. If a suitable binding partner is found, the energy is “consumed” or absorbed in the other compound. The photoactive, nanoscale material thus returns to its initial state, while the second compound is in an altered, reactive state. This form of activity is exemplified in Figure 9 for the generation of reactive oxygen (singlet oxygen).

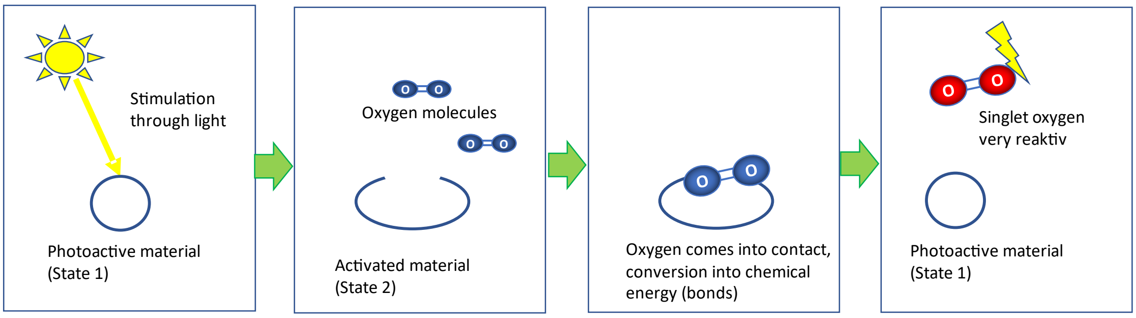

Figure 9: Photoactive, nanoscale materials generate reactive oxygen molecules.
Source: Own illustration

Benefits

Among other things, research is being conducted into how this activity can be used for disinfection. Reactive oxygen can destroy viruses as well as bacteria and the so-called biofilm in which they occur. The formation of reactive oxygen can be controlled both temporally and spatially by light dependency. This mechanism could also be used in sewage treatment plants to destroy organic material that is difficult to break down. Equally, it could be used in drinking water treatment and disinfection.

With photoactive, nanoscale materials, bacteria, viruses and other microorganisms are attacked by reactive oxygen. This quickly and “universally” destroys the cells or organic material. This means that the risk of organisms becoming accustomed to this mechanism or developing defence mechanisms (resistance formation) is very low.

Risks

As also shown in the previous examples, environmental and health risks can arise if the building blocks used in the active, nanoscale materials have (eco-)toxic properties. This is the case at least with some of the compounds whose potential applications are currently being researched. Moreover, in addition to the desired degradation of organic compounds by the reactive oxygen, new compounds could also be created that have toxic properties.

3.4.2 DNA and RNA - special building materials for active, nanoscale materials

DNA and RNA molecules are popular “building materials” for nanoscale structures. This has various reasons, such as:

- The molecules are cheap and easy to obtain.
- It is possible to produce the most diverse 3D structures in a self-organised reaction.

- DNA and RNA can be stabilised well.
- Degradation mechanisms exist for these naturally occurring polymers.

DNA and RNA, with one exception, consist of the same nitrogenous bases (cf. Figure 10). When nanostructures are made from DNA, the fact that two types of bases form bonds with each is taken advantage of: A long scaffold strand (single-stranded) is mixed with various short and single-stranded so-called clamp strands. The clamp strands bind to different parts of the scaffold strand by "pairing" the compatible bases. In order for this binding to be spatially possible, the scaffold strand must "fold". This creates three-dimensional structures. It is possible to compute the needed base sequences of the clamp strand if the base sequence of the scaffold strand is known and the target structure is defined.

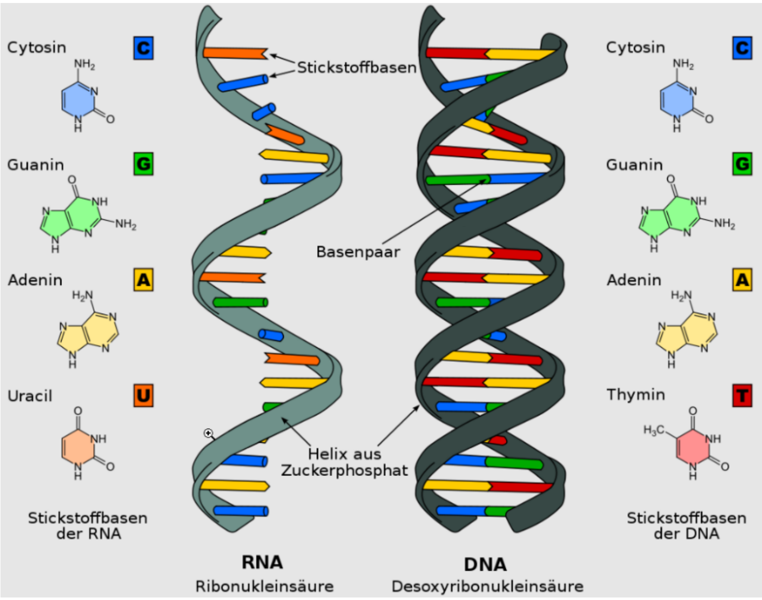

Figure 10: RNA and DANN molecules and their components (nitrogen bases)
Source: https://commons.wikimedia.org/wiki/File:Difference_DNA_RNA-EN.svg

The stimuli to which DNA and RNA objects react depend on their (three-dimensional) structure and possible other molecules that may be linked to them. Their activity usually consists of a change in structure that either releases or requires energy.

Benefits

DNA structures could be used for various applications, including as nanocarriers (cf. Chapter 3.1) or sensors in diagnostics. Research is being conducted on "nanorobots", which can be considered to be molecular tools for processing materials, e.g. the production of (other) nanostructures. Many other uses are conceivable and some are under development.

Risks

Synthetic DNA or RNA structures are not "genes"! Scenarios of self-replicating DNA structures that take control of humans are not realistic. Since (the building blocks of) DNA and RNA occur naturally, toxicity is not to be expected. However, little is known about the behaviour of DNA and RNA objects in the body and in the environment.

Since they are produced with the aim of stability, they can only be compared with naturally occurring DNA and RNA to a limited extent.

4 Are active, nanoscale materials regulated?

Active, nanoscale materials are in principle covered by chemicals legislation and must therefore meet the same legal requirements as other chemicals. However, some specific features of nanoscale materials suggest that a review of the legal framework is necessary.

How strictly a chemical is regulated depends on what properties it has; the more (eco-)toxic chemicals are, the stricter the requirements. The law also prescribes which properties have to be determined using which methods. The extent of required (hazard) information depends on the tonnage in which a chemical is produced.

It is possible that (eco-)toxic properties of active, nanoscale materials are not or cannot be tested, and thus remain undetected. This means that for such chemicals no so-called chemical classification[8] can be done. Without a classification, requirements for (specific) risk management are normally not triggered. Possible reasons for the lack of (testing) information for a classification are:

- In the case of small production quantities, there is no obligation to test and determine the hazardous properties.
- For polymers, which are frequently used in active materials, there is currently no obligation9 to determine the hazard.
- The test methods are not adapted to the special features of these materials. Therefore, they do not provide reliable results or are not applicable at all.
- Active, nanoscale materials are present in (at least) two states that (can) have different properties. The existing test systems can neither test this, nor can they predict further degradation processes that may take place.

Thus, it is not always ensured that the risk management measures required for hazardous chemicals are also effective for active, nanoscale materials. Furthermore, there is a lack of guidelines and specifications on how the safety of products in which active, nanoscale materials are used can be checked. Therefore, there is a need for improvement and adaptation of the instruments for the implementation of chemicals legislation.

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[8] Chemical classification is an evaluation process in which information on the toxicity and ecotoxicity of chemicals from tests is compared with criteria for various adverse effects, such as carcinogenicity, reproductive toxicity or allergenic effects. If the test results exceed certain thresholds, a substance is "classified" for that adverse effect.

[9] Currently, chemicals legislation is being revised at EU level. The introduction of an obligation to identify information on the hazards of (selected) polymers is likely.

5 Summary

Active, nanoscale materials are chemical substances or compounds that are smaller than 1000 nm in at least one dimension. During their application, they absorb and convert energy. This changes their structure or energy state. Active, nanoscale materials can consist of various “building blocks” ranging from metals or salts to DNA.

The activity of nanoscale materials is triggered by an external stimulus, e.g. light or an electrical voltage. Depending on the material, energy can be converted into chemical bonds, radiation, movement or electrical energy. Often this is reversible, meaning the activity can be carried out again and again. The nano scale of the materials can be crucial for the function for two reasons: a) the activity is based on ‘nano effects’ (e.g. quantum dots) or b) the functionality requires a very small size (e.g. nanocarriers).

Currently, medicine is the most important research and application field for active, nanoscale materials. Research is being conducted in pharmacology, diagnostics and medical products. Other important areas are electronics and information processing.

Active, nanoscale materials can make existing technologies more efficient, improve their quality or enable entirely new technological approaches. Possible risks can arise from (eco-)toxic building blocks of the materials if they come into contact with humans or the environment. In addition, the recovery of the materials is difficult for various reasons, which can be problematic for rare chemicals.

In principle, active, nanoscale materials are covered by existing legislation. However, it is not (always) ensured that the potentially (eco-) toxic properties of active, nanoscale materials are also determined. There is a need for legislators to examine this.

The development of active, nanoscale materials will progress in the coming years. For many societal challenges, active, nanoscale materials seem to be able to make important contributions. More information on possible risks is needed to ensure that only those active, nanoscale materials are applied whose benefits exceed the risks to humans and the environment.

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Galstyan, Anzhela: Light against antibiotic resistance: imaging, characterisation and biological properties of new photoactive materials.

Giese, Bernd: What are active nanoscale materials?

Hermann, Andreas: DNA hybrid materials for nanomedicine

Kolarić, Ivica: EAP NC - HUMAN MASCHINE INTERACTION

Tietjen, Lars: Regulatory Aspects of Active Nanoscale Materials in REACH and CLP Regulation

Wedel, Armin: Quantum Dots - a new class of materials for display technology