Content Unit
[What is nanotechnology?]

Name of author: [Christopher Fischer, Andrea Deißenberger]
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What is nanotechnology?

First introduction

THE BIGGER THE BETTER? Sometimes being smaller is better. That accounts for so called nanomaterials. These materials are in the range of 1 to 100 nanometres, but what is a nanometre? Nano is Greek for dwarf which means that a nanometre is a billionth of a meter. That is incredibly small. For example: Your fingernails grow at a speed of circa one nanometre per second. More examples for the better understanding of this hard-to-imagine size will be given throughout this unit.

Practical relevance – This is what you will need the knowledge and skills for

In this unit you will learn, what nanotechnology is and what it is used for in general. You will get an insight on how small a nanometre is and how the size of the nanoparticles gives them remarkable properties. Moreover, you will learn about the history of nanotechnology and that it can be found in various fields of modern research and technology.

Overview of learning objectives and competences

In „Understanding the nano dimension" you will learn how small the world of nanotechnology is.

In "History of nanotechnology" you will get to know nature as the first great nanotechnologist and how we imitate many of those principles until today.

"Nanotechnology in different disciplines" gives an insight on the various branches of science, making use of nanotechnology.

Learning objectives	Fine objectives
LO_What is nanotechnology?_01: Understanding the nano dimension	FO_What is nanotechnology?_01_01: The size of nanoparticles FO_What is nanotechnology?_01_02: Surface to volume ratio FO_What is nanotechnology?_01_03: Size and properties
LO_What is nanotechnology?_02: History of nanotechnology – nature as the greatest nanotechnologist	FO_What is nanotechnology?_02_01: Who knew this was already nanotechnology? (before the term was invented) FO_What is nanotechnology?_02_02: How it became famous (mid 20th century) FO_What is nanotechnology?_02_03: What is achieved nowadays
LO_What is nanotechnology?_03: Nanotechnology in different disciplines	FO_What is nanotechnology?_03_01: Nano in chemistry FO_What is nanotechnology?_03_02: Nano in physics

	FO_What is nanotechnology?_03_03: Nano in medicine FO_What is nanotechnology?_03_04: Nano in electronics

1.Understanding the nano dimension

Nanotechnology is HUGE. It impacts different disciplines in science. It is already applied in multiple areas of daily life and made its way into one of the fastest growing markets in the world. Ironically all of those useful characteristics come from very tiny materials – the nanomaterials. These materials are in the range of 1 to 100 nanometres. But what is a nanometre? Nano is Greek for dwarf and it means that a nanometre is a billionth of a meter. To get an idea of how small a billionth of a meter is we will have a look at the following example.

Definition
Nanometre One nanometre is a billionth of a meter. In other words one nanometre is 0.000 000 001 meters.

So let us try to attack this problem by making a comparison to the "meter-sized" world we are living in. From time to time we measure our own body length and we express the number in meters as the best fitting unit at this point. To come closer to the nanometre-scale we could have a look at smaller parts of our human body. So if we choose our nose, fingers or ears we agree on centimetres as a good unit.

But we are definitely still far away from a nanometre. The maybe smallest example most of us carry around are the hairs. Let´s accept this as the tiniest thing we could find on our own body. Think of the fact you barely can see the diameter of it with your eyes. You will realize how small a nanometre is by considering that a single human hair is still 80.000 nanometres wide.

Important
The size of nanomaterials Nanomaterials are 1-100 nanometres small. This is exceptional small size enables all of the great properties of nanomaterials.

But how do all those special properties come along with those nano-scaled materials? The first important phenomenon is the high surface to volume ratio. This increases rapidly if you downsize materials to an extend smaller than 100 nanometres. As a result, the surface properties become more and more important. You can understand this by imagining that atoms which are not in contact with the surface behave different properties compared to the surface atoms. Letter get in touch with their environment and are involved in different interactions. This can lead to more efficient material classes. For example, the silver element is used because of its excellent germicidal (= capacity to kill germs) properties. If you want to apply this material in bigger scales, you can imagine the very high costs of larger amounts of silver. That is a problem that can be solved by downsizing bulk-silver to nanoparticles with more surface atoms. With this method a smaller amount of "nano-silver" can have the same efficiency as a bigger amount of "bulk-silver".

Important
Surface to volume ratio Nanomaterials show very high surface to volume ratio if they are smaller than 100 nanometres. This has direct influence on chemical and physical material-properties.

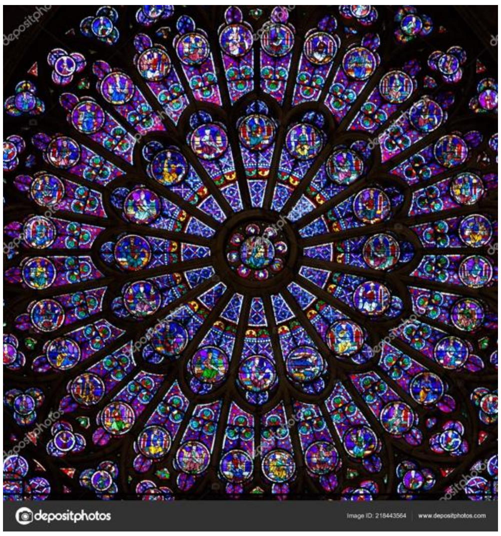
Quantum effects can begin to dominate the behaviour of matter at the nanoscale - particularly at the lower end (single digit and low tens of nanometres). An object which is that small is a quantum mechanical object. That means that it is not obliged to the classical laws of physics anymore. Instead, it obeys the rules of quantum mechanics, which can lead to significant changes in optical, electrical or magnetic properties. Let´s have a look at an example again to make things clearer.
Such a versatile material is titanium dioxide. When you use this as a bulk material it is a very good reflector of every visible wavelength of light. Thus, you can find titanium dioxide as a pigment in white paint to guarantee you a beautiful shiny white wall.

Things change rapidly, when we look at the small titanium dioxide nanoparticles, which lose their reflector ability in the visible area completely, just ultraviolet light is reflected which makes the material transparent again. Those modified characteristics fit perfectly for the application in sun cream. They keep away the dangerous UV-light from your body, while still being transparent. So even if those nanoparticles are the exact same chemical compound the optical properties are highly dependent of the particle size.

Important
Size and properties Nanomaterials at the lower end of the nanoscale (lower than approximately 50 nm) are quantum mechanical objects and change their optical, magnetic and electrical properties.

2.History of nanotechnology – nature as the greatest nanotechnologist

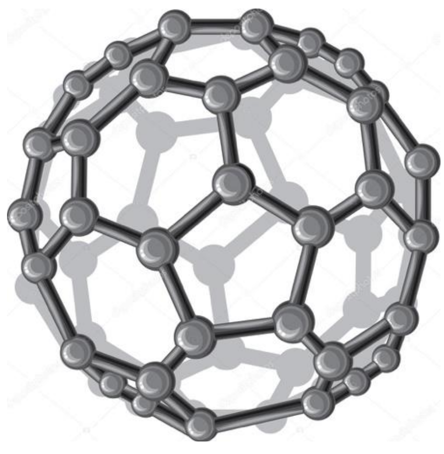
The history of nanotechnology starts way before the term itself was invented. For instance, medieval artisans back in the 10th century used silver nitrate and gold chloride to give stained glass its yellow or its red look. Nowadays we know that those elements act as quantum dots and reflect a special wavelength of the light leading to that colour.



A later example from the 13th to 18th century are the "Damascus"-saber blades which are popular for their extraordinary durability and sharpness. A feared weapon back in the days is nowadays a fascinating example for applied nanotechnology. Researchers found that the steel contains cementite nanowires encapsulated by carbon nanotubes which could be responsible for its strength and resilience.

Remember
History of nanotechnology The history starts way before the area was named "nanotechnology". There are plenty of historical examples where nanotechnological methods were applied, although there was no deep understanding of the science behind.

The modern nanotechnology started with the discovery of colloidal "ruby" gold by Michael Faraday. In 1875 he showed that, depending on the lighting conditions, a solution of nanostructured gold appears in different colours. With growing interest in big effects of very small particles Richard Feynman gave the first lecture on technology and engineering at the atomic scale at the California Institute of Technology. In 1959 a name for this field was still not present and so he named the lecture "There´s plenty of Room at the Bottom".
Because more and more scientists around the world began to speak about this new emerging research area, Norio Taniguchi – a professor at Tokyo Science University – named it "nanotechnology", back in 1974.
Up to this point it is clear that scientists were the driving force for understanding and developing nanotechnology in the beginning. That changed in the 1990s, when the first nanotechnology companies began to arise. That came along with the development of the information society, where more and more data is produced, saved and processed.
Nanotechnology also made it possible for scientists to receive their greatest honour with the Nobel Prize in Chemistry in 1996. Harold Kroto, Sean O´Brien, Robert Curl and Richard Smalley received the award for the new class of molecules named "fullerenes", which only contain carbon atoms. The most famous example of this group is the Buckminsterfullerene. The latter is also called "buckyball" because of the memorable soccer ball shape with approximately a single nanometre in its diameter.



Remember
Nanotechnology getting famous

The Nobel prize is the highest award you can receive in science and was granted for the research about nano-scaled fullerenes in 1996. It showed that the world of science understood the potential of those small molecules.

After scientists and the first companies realized the potential of nanotechnology, also governments became aware of this highly innovative discipline. In 2000 President Clinton launched the National Nanotechnology Initiative (NNI) to organize federal Research and Development efforts and to boost commercial establishment of nanotechnological applications.
So, we can conclude that the history of nanotechnology is definitely a huge success story. But what is achieved nowadays? Have we already seen the peak of scientist's creativity and exploited the full potential of nanotechnology itself or are the best days yet to come?
Actually, there are a whole bunch of examples that indicate a bright future for nanotechnology. For example, in 2012 the government of the United States planned a 2-billion-dollar investment in research, because of the strategic importance of that area. And all of those efforts seem to bear fruits. So, the global market of applications including nanotechnology was estimated with a worth of a trillion dollar in 2015. Also, Europe sees nanotechnology as a key technology for the future. Especially the European Union is investing in that area. An example is their latest funding projects is "Horizon Europe", which is aiming for innovation in functional materials, communication technology and health related topics. It initiates companies and researchers to team up and work together, regardless of inner-European borders or the specific disciplines they are working in. That interdisciplinary strategy could have an impact on solving longstanding problems as in medical or energy applications. That discussion will follow in the next sections.

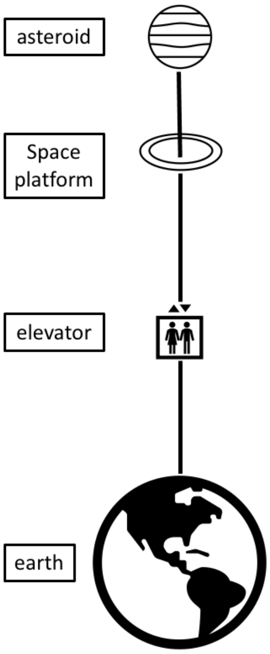
Important

What nanotechnology has achieved in the modern era

After long years of trying to understand this nano-scaled world, the efforts are worthwhile. Nanotechnology made its way into an economically established field.

3.Nanotechnology in different disciplines

In this topic we will acquire knowledge about nanotechnology as a highly multidisciplinary field. That is another remarkable feature. This means that chemists, physicists and medical scientists are equally attracted to nano and every one of them makes use of the laws of the nano-scaled world in their own way. So, let us have a look at the impact nanotechnology has on the different branches of science with a few examples.
First, we will examine nanochemistry. The main tasks of nano-chemists are to synthesize, analyse and characterize nano-scaled, chemical compounds. The modern world requires countless numbers of new materials which have to perfectly fit a single special application. In general, the design of materials with well-defined characteristics is a permanent research area for them. As we mentioned earlier, the small size of nanomaterials comes along with unique behaviour and attributes. This opens up new opportunities for solving problems where conventional materials reached their limits. Let´s illustrate this with an example: The space elevator. What is that and what do we need nanomaterials for? A space elevator is a method for putting things in orbit without using a rocket. Analog to the elevators we know from skyscrapers it could be used for things or people. The motivation to build such a thing is to avoid the immense transport costs which are a part of space flights. So how does such an elevator work? Basically, there is an extremely long cable, which is carrying the elevator. That is attached to the earth somewhere at the equator and to an asteroid. In-between could be a space platform, where we want to go.



Even though this sounds like a science fiction movie, this is an earnest ambition. For instance, NASA promises high prize money, if someone solves one of the problems, which bar the way to the realization of a space elevator. One of the longstanding problems is to develop the cable. You have to encounter that it has a length of 90.000 kilometres and so it has to be stronger than any normal-sized cable on the face of the earth. Now this is where nanomaterials come into play. More precisely, the fullerene molecules, which we already heard about earlier. In this case the carbon nano tubes show high potential as a material to build such a strong cable. Some researchers already developed samples, which seem to be multiple times stronger than steel.

Remember

Nanotechnology in chemistry

Chemists synthesize, analyse and characterize nanomaterials. They can influence the attributes of nanomaterials, so that they fit for special applications.

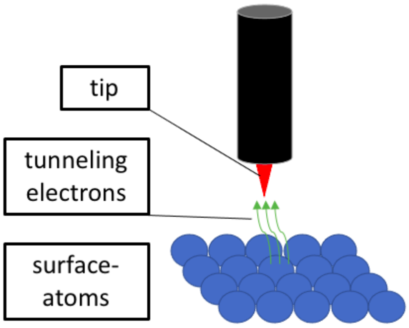
Now we learned that one method to form nanomaterials is the chemical synthesis. In most of the cases we would call that the “bottom-up-approach”. That means that you start off with atomic or molecular units and stick them together until you end up on the nanoscale. Distinctly different from this is the “top-down-approach”. Maybe this is more like the method of a physicist. Here you start with the bulk material or a bigger particle and crush it down to nanoparticles. The method can be compared to a sculptor, who uses a big starting material and breaks it down until he reaches the size and shape he wants.

Excurse

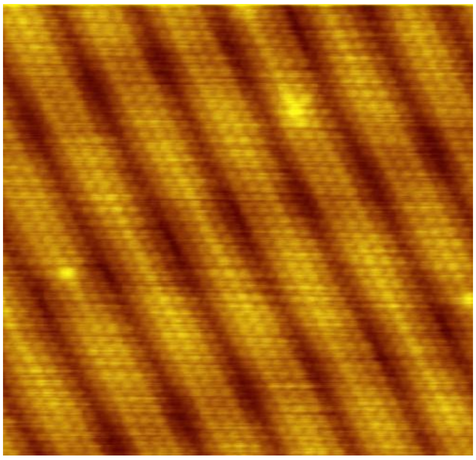
Top-down vs. bottom-up

The top-down-approach goes from big to small. A bulk material is crushed until you end up on the nanoscale. The bottom-up-approach is connecting small atomic or molecular units to bigger structures with the size of nanoparticles.

Besides this concept of forming nanomaterials, there are more points of contact between physics and nanotechnology. A famous method for analysing nanomaterials is the scanning tunnelling microscopy (STM). This technique is so impressive, because it makes the surface of nanoobjects visible to the human eye. Just remember the beginning of this learning unit, where we made clear how small a single nanometre is. Also remind yourself, that the surface-characteristic of very small particles gets extremely important in comparison to bulk-materials. Now it should be clear why this microscopy technique fits so well into nanotechnology. STM basically measures the interaction of the tip and the probe-surface and creates a picture with that information. The remarkable results you get with that tool are again only possible because of the special behaviour of nano-sized objects. We already mentioned in the beginning that they obey the law of quantum mechanics. The important effect here is “tunnelling”. For a better understanding of this concept let´s imagine we throw a ball against a wall. In our classical world that ball is going to stop at the same side of the wall – the side we stand on. In the quantum mechanical world, if the wall is thin enough and the ball is fast enough, there is a certain possibility for the ball to go through the wall (without destroying it). And this tunnel-effect is applied in STM. The tip of the microscope “sucks” electrons from the surface-atoms of our nanomaterial, although the distance between the tip and the surface would forbid that in a classical world. That distance is analogue to the wall in our classical comparison.



Fortunately, our tip and the probe are so small that they act as quantum objects which makes it possible for the electrons to be “sucked” out of the surface across the distance. But how do we get a signal from this effect? To understand this, we must know, that we apply a voltage between the probe and the tip. Therefore, if the tip is at very short distance to the probe-surface the electrons can tunnel into the tip and we create flowing electrons – a current. Latter can be detected and gives us our signal. But how do we get the promised picture of our surface? Simply by moving the tip over the whole surface and get the current for every single point. And when we think of the fact, that we get a higher current for points where the tip-surface distance is small (and vice versa) we can draw conclusions regarding the surface structure. In a classical world the tip would have to touch the surface to create a current. This contact could lead to damage of our probed material. Now we understand the very smart principle of STM and why it is so helpful for nanotechnology.



STM-Picture of a gold surface

Remember
Nanotechnology in physics Physicians made it possible to scan surface-structures with STM. Considering that the surface-characteristics of nanomaterials are weighing more heavily than in bulk materials, we can understand the importance of that analysing method.

Moreover, nanotechnological applications could potentially find answers to some longstanding medical problems. For example, by using certain nanoparticles it is possible to optimize the transport of drugs in our system. Those nanoparticles are nano-capsules, and they encase the active substance.

Just like a Taxi, which is driving to a defined destination, the capsule delivers the drug directly to the intended place in our body. This comes along with some huge advantages. Because through this efficient targeting it is possible to have an equal effect at smaller dosage. The injection of large amounts of drugs is not necessary anymore, which reduces the risk of side effects drastically. Moreover, small particles can be designed to pass the blood-brain-barrier. Latter is always a difficulty for drugs, which are supposed to deal with brain tumours or neurological diseases. In this context nano-diamonds have been very promising. They are coated with the protein "albumin", which is a natural component of human blood. With this modified surface the nano-diamonds are not identified as foreign bodies and get through the natural barrier into the brain. Also, the drug molecules can be attached to that surface-proteins, which paves the way for them into the brain.
Nanotechnology also opens new approaches in terms of cancer therapy. As cancer-disease are one of the permanent worries of the modern world, many scientists put their efforts into research in this area. Even though this happens for many years now, nanotechnology is one of the few examples, which is operating with a totally different concept as the established methods, like radiotherapy. Basically, the new therapy-method uses iron oxide nanoparticles, which are brought directly into the tumour tissue. When you locate them in an electromagnetic field, the nanoparticles get hot. This causes cell death or at least strong damage of the tumour cells. The adjacent tissue isn't affected with this method, which is a huge advantage compared to the damage caused by typical radiotherapy.

Remember

Nanotechnology in medicine

Nanoparticles open new methods for cancer therapy. Also nano-capsules show way more efficient targeting in terms of drug delivery. This allows mild dosage and leads to less side effects.

Finally, we want to get an insight of "nanoelectronics". Its main task is the development and production of miniaturized integrated circuits. With the microelectronic structures getting smaller, it is possible to increase their performance, while reducing the costs at the same time. That is the reason why electronic structures became increasingly smaller over the years and we came from "microelectronics" to "nanoelectronics". Latter is mainly including structures smaller than 100 nanometres. Three examples of important nanoelectronics research-areas are given ensuing. An ongoing task for scientists is to further miniaturize the transistors used on integrated circuits. This makes it possible to merge the power of multiple "normal-sized" computers nowadays in much smaller structures in the future. Another aim is to improve the density of memory chips. You can imagine that in our digital world, massive amounts of data must be saved and processed. And because of that the efficiency of memory chips must withstand this growth.

The final example is the optimization of display screens. That means, that we must reduce the power consumption, the weight, and the thickness of the screen at the same time.

Remember

Nanotechnology in electronics

Nanoelectronics mainly focuses on the miniaturization of electronic structures to increase their performance and reduce the costs.

1.Save knowledge

Summary

You reached the end of the content unit about “**What is nanotechnology?**”. As there was a lot to learn, please receive a quick repetition of the most important things you learnt about this topic:

Nanomaterials have special properties, that come with their small size of 1 to 100 nanometres. For comparison: An average hair has a thickness of 80.000 nanometres. When an object gets really small, the surface of the object, compared to its size gets bigger. That’s what makes most nanomaterials so special. Even with a small amount of nanomaterial, a big effect can be achieved.

Examples of nanomaterials can be found even before anybody even knew what nanotechnology even was. When scientists found out that objects at the nanoscale had different properties than the same material at a larger scale, they looked deeper into these materials and adapted the concept. Nowadays, nanomaterials can be found in a plethora of applications and research in this area is done all-over the globe.

Nanotechnology is not only found in one discipline of science, but can be seen as a bridging technology over different fields: chemistry, physics, medicine, electronics, etc. The following chapters will give you a deeper dive into the nano-world and will also show you, where nanotechnology crosses your everyday life.