Peering into the Unseen

When new technologies literally touch us, the general discussion about their opportunities and risks becomes more intense. Nanotechnology applications in medicine, nutrition and cosmetics, for example, are particular subjects of public debate. Our authors have observed that there's a lot more to these debates than just scientific facts.

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Structures about 10,000 times smaller than the diameter of a human hair – that is the order of magnitude for research in nanotechnology, where the typical unit of measurement is the nanometer, one millionth of a millimeter. Nanoscience – the name derives from the Greek word *nános* (dwarf) – promises us new materials, surfaces with customized properties, and machines the size of a molecule. The societal issues it raises are as fundamental as the prospects are revolutionary. The questions have no right or wrong answers.

> Research provokes questions to which there are no right or wrong answers

Following years of intense and – particularly in Germany – extremely successful research, we find ourselves now in a phase when these new nanoproducts are coming onto the market. Actually, there are already several hundred items that contain nanoparticles, particles no more than millionths of a millimeter in size. Tennis rackets and golf clubs are made more stable by nanoadditives in the plastics, sunscreen with nanoparticles of titanium dioxide offers particularly effective UV protection, nanoparticles of silver have an antibacterial effect in textiles and foodstuffs stay fresh longer thanks to nanopackaging. Printer toner and colloids, both of which are "nano," have existed for years.

"Nano" can also describe the existence of particular capabilities that arise due to particular properties of matter on the scale of atoms and molecules. This applies both to inanimate objects and to living systems. The growing understanding of nanosystems is now being applied for the first time in the complex area of self-organizing, living systems, and thus also in nanomedicine.

The potential is as great as the unknowns. Nanoparticles have specific strengths, but they conceal unfamiliar risks, as well. Nanomedicine entertains visions of tiny transport capsules intended to accurately deposit medications in the body, but there are reservations about what happens to the nanoparticles after they have done their work. The tiny particles are able to penetrate cell membranes, and may become concentrated in organs, or provoke inflammations in the respiratory tract.

Nano-objects have always existed, long before the name came into being. In fact, all medicines are, in principle, nano-based if they address the molecular

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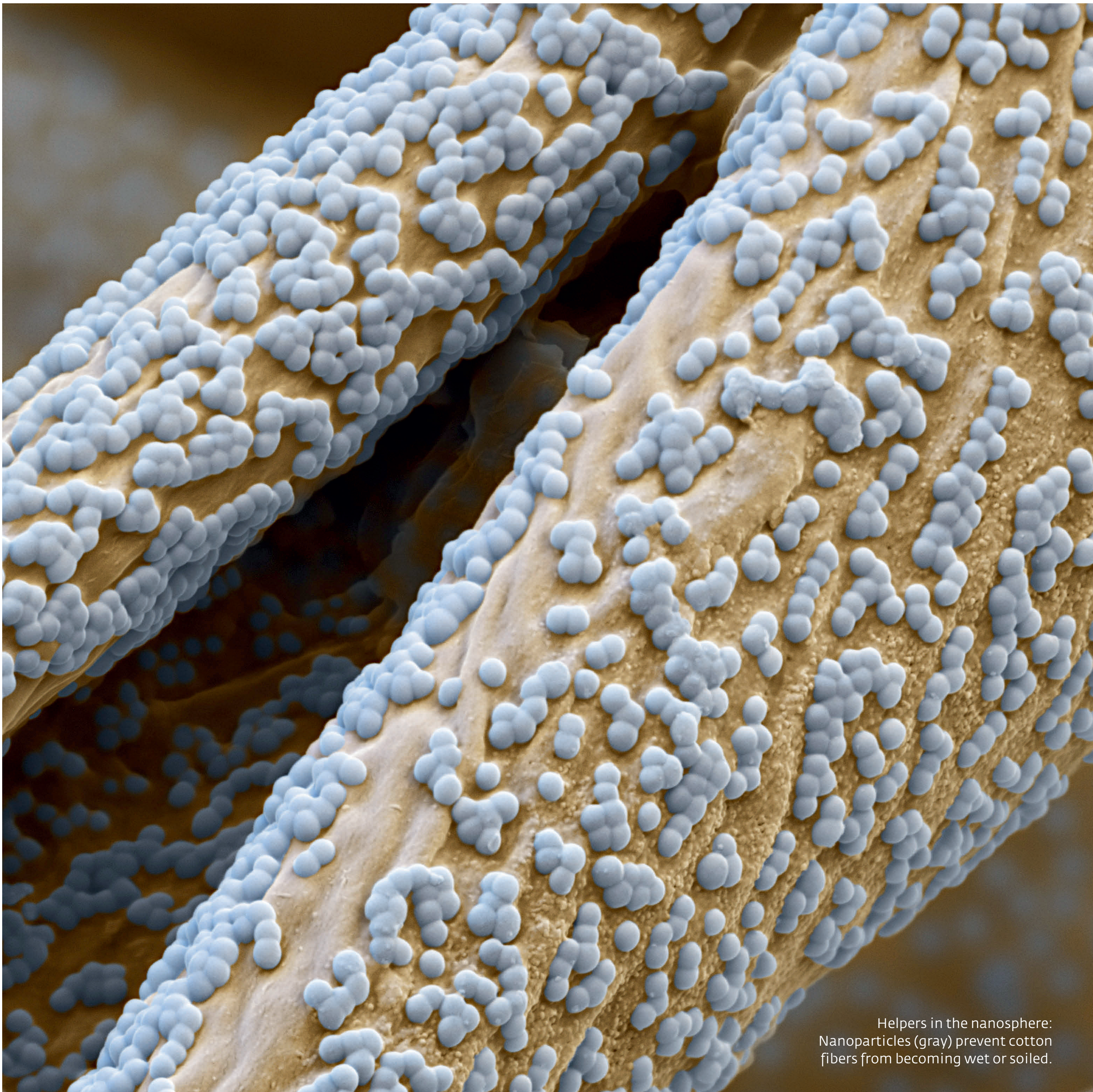


Helpers in the nanosphere: Nanoparticles (gray) prevent cotton fibers from becoming wet or soiled.

causes of diseases. The molecular interaction of antigens and antibodies – the energies exchanged and the forces between them – is medical nanotechnology and is instrumental in the development of treatments, for example. Drug delivery systems may clear the way to personalized medicine.

Another field with high expectations is nano-based cancer therapy. The hopes and expectations are especially high here. As an example, nanoscale systems have been developed in recent years that effectively distribute active pharmaceutical agents in the body and deliver them to the correct locations. A nanoparticle cancer therapy from German company MagForce, for instance, has reached the approval stage for certain restricted indications. And there are already medications contained in lipid vesicles. Nanoparticles based on polysaccharides or polymers can also serve as carriers. Ideally, the active agent not only reaches the right place in this manner, but is also released at a specified time, as well.

> Balanced communication is essential to clearly separate fact from fiction

Scientists are hopeful that, in the future, greater molecular knowledge and understanding of the causes of diseases will bring many benefits, including better chances of recovery for damaged tissue, in that nanomaterials and adult stem cells will be employed to synthesize new skin, new bones, nerves and new blood vessels. Self-organizing behavior will also one day be utilized in nanomedicine, for example once we better understand the process by which wounds heal.

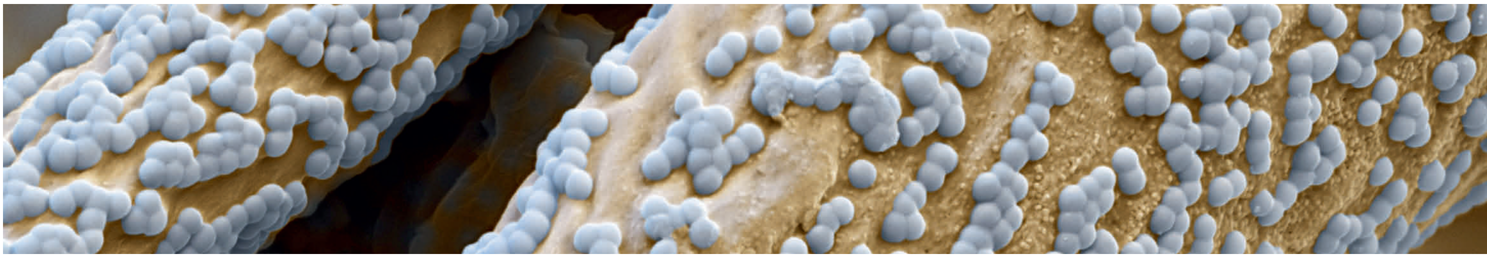
In addition to therapy, nanoresearch will also lead to advances in diagnostics, such as in the area of imaging procedures. Supermolecular systems are already being routinely employed in X-ray and NMR diagnostics today. Nanoscale diagnostic units should facilitate simple and fast medical examinations. DNA- and RNA-based biosensors for nucleic acids and proteins are conceivable, as is information processing with DNA-based reagent networks for analyzing complex mixtures of biological molecules. Nanomaterials and nanosurfaces offer new avenues for implants and prosthetics.

"Drugs with no side effects, cures for cancer and cardiovascular diseases, long-lasting implants for bones and teeth or for stimulating neural activity all promise a healthy future and sound almost too idealistic to be true," says risk researcher Antje Grobe in Stuttgart. Nanomachinery and nanorobots that operate in the bloodstream, for instance, are currently still a dream of the future, but they have particularly caught the public's imagination.

Balanced information and communication about the methods, uses and risks of nanomedicine are essential – not least to clearly separate fact from fiction. Nanomedicine certainly won't transform us into superhumans, but it may one day revolutionize the above-mentioned drug delivery systems if drugs – packaged in nanoparticles – can selectively target cells at the desired treatment location by recognizing surface characteristics.

The word "nano" has served as an effective term in garnering political funding for research, but certainly a more exact definition is needed when it comes to matters of product classification and consumer protection. Yet this is not as easy as it might seem. Should nanoparticles be defined solely by their dimensions, or is their function and reactivity more relevant, for instance for toxicological testing? Are the usual quantitative definitions of threshold values sufficient for "nano", based on the maxim that "the dose makes the poison"? Or do we have to apply the number of particles and their surface areas in addition to their bulk quantity as the relevant gauge, since these dimensions determine reactivity?

The EU Commission presented a suggested definition for nanomaterial in October 2011: a nanomaterial is "a natural, incidental or manufactured material containing particles in an unbound state, as an aggregate or as an agglomerate, and where, for 50 percent or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm to 100 nm. […] In deviation […], fullerenes, graphene flakes and single-wall carbon nanotubes with one or more external dimen-



sions below 1 nm shall be considered to be nanomaterials."

That sounds plausible initially, but it offers various points for criticism. This definition renders all particles of a certain dimension generally suspicious. A sharp limit such as 100 nanometers is arbitrary. Why not 30 or 500 nanometers? Wouldn't it be more reasonable to develop a catalog of risk-relevant material properties?

Such questions of definition may appear to be abstract at first glance, but they aren't abstract in the least! There is, for instance, a new EU-wide cosmetics regulation coming into force this year, according to which all components in the form of nanomaterials must be clearly listed in the ingredients. "The Cosmetics Regulation requires labeling of nanomaterials (name of the ingredient, followed by 'nano' in brackets) in the ingredients list," to quote from this paper.

More than half of all Europeans haven't yet heard of nanotechnology. And although the situation is better in Germany, even here, more than a third of the population has no concept of nanotechnology, as shown by the latest opinion polls conducted by the EU's Eurobarometer. Even so, it can be seen in Germany that the attitude of the majority of consumers continues to be positive – even if the increasing level of knowledge is causing growing differentiation in people's opinions, depending on the field of application. The proportion of those having difficulty reaching an overall opinion is considerable.

So how will public opinion evolve? Relevant studies continually show that more information doesn't automatically create more approval, but rather tends to polarize the existing positive or negative attitudes. Studies of this nature also make it clear time and again that how people relate to nanotechnology depends on many different factors. Communication can hardly dispel what doubts there are, since they derive from people's fundamental anxieties and attitudes. And these, in turn, have proven to be remarkably stable over time.

There have already been several waves of media attention whose starting point was not so much the concrete hazards, but the opinions and position papers complaining about these hazards. For example, a background paper entitled "Nanotechnology for Mankind and the Environment" (*Nanotechnik für Mensch und Umwelt*) published by Germany's Federal Environment Agency (Umweltbundesamt, UBA) in October 2009 was interpreted by many in the media as a warning about nanotechnology. For example, the front page of the Süddeutsche Zeitung on October 21, 2009, as well as Spiegel Online proclaimed: "German Federal Environment Agency issues nanotechnology warning." After a few hours of research, the online portal was able to summarize the matter more realistically: "Federal Environment Agency qualifies its nanotechnology warning." In the Tageszeitung of October 23, 2009, a story by science journalist Niels Boeing put it in a nutshell: "Nanotechnology harbors several risks. However, these have been known about for a long while and are only half the story."

> The situation is growing more and more confused with the increasing number of studies produced

The special report entitled "Precautionary Strategies for Managing Nanomaterials" (*Vorsorgestrategien für Nanomaterialien*) by the German Advisory Council on the Environment two years later read similarly: grounds for applying the principle of precaution are presented by the "abstract concern" that exists. No wonder environmental groups not only demand more transparency, but also want to completely ban nanomaterials from foodstuffs and cosmetics until the harmlessness of nanomaterials has been proven. It is for this reason that nanoparticles are prohibited in foodstuffs and cosmetics from agricultural land certified as organic by the *Naturland* seal.

The German National Academy of Science and Engineering (acatech) Topic Network on Nanotechnology has been observing the debate on the opportunities and risks associated with nanotechnology, as well as the curious situation that the issue is growing more and more confused with the increasing number of studies produced. This is why we decided – together with the Leopoldina National Academy of Sciences and the Union of the German Academies of Sci-

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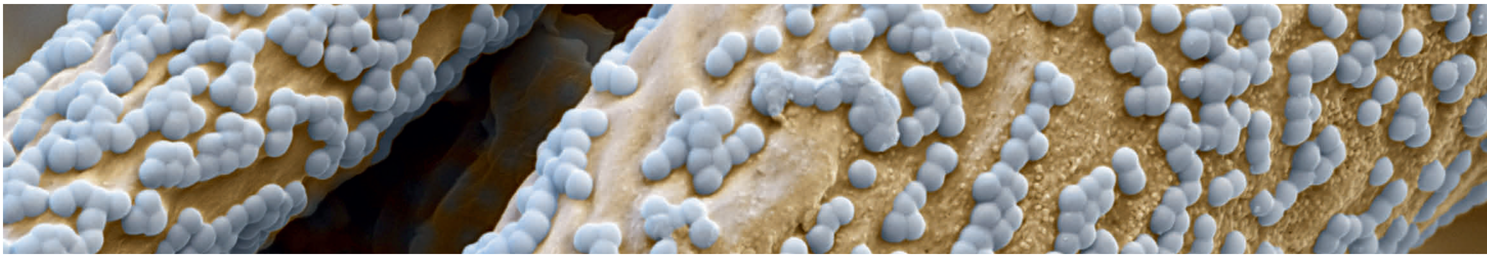

ences and Humanities – to take a look at the applications that directly affect us as human beings: nanotechnologies in medicine, cosmetics and nutrition literally touch the consumer.

Many questions about opportunities, risks and solutions to problems arise at this point. What can we expect from nanomedicine? What effects do nanomaterials in cosmetics have? How does "nano" taste – and is it healthy? Will we soon need to read a leaflet enclosed with consumer products, as we do now with medicines? As a result, an academy symposium was held in Munich in late 2010, with the findings recently published as a volume of essays. In addition to a presentation of the scientific and technical opportunities and challenges involved, a discussion of the communication aspects took up considerable space.

Ortwin Renn, a technology sociologist in Stuttgart, and his associate Antje Grobe identified three points during this discussion that are important for dealing constructively with nanotechnology (as with every other new technology). First, they made it clear

If risk is to be assessed rationally, the best systematic knowledge must be incorporated

that knowledge today is indeed ambiguous and uncertain, but in no way arbitrary. In the context of risk assessment, it is especially important to define the bandwidth of knowledge that is methodologically tenable, and to separate the absurd from the possible, the possible from the probable, and the probable from the certain.

Second, Renn and Grobe emphasized that expert knowledge and lay perceptions should be categorized as mutually complementary rather than contradictory. They explained that the acceptability of risk can't be determined by means of expert knowledge, but that reasonable expert knowledge is an absolute prerequisite to being able to reach a carefully considered judgment about acceptability. Responsible action must be measured against how objectively, adequately and morally justifiably decisions are made, considering the uncertainties. If one wants to judge risk rationally and fairly, it is, they say, essential to apply ethically justifiable evaluation criteria and standards, as well as to integrate the best available systematic knowledge.

Third, decisions about the acceptability of risks are ultimately always based on subjective considerations that incorporate people's knowledge and values. As Renn and Grobe put it, discourse without a systematic base of knowledge is but empty talk, while discourse that ignores the moral quality of the potential actions helps immorality gain acceptance. Morality and objective expertise must both be integrated equally into the discourse on risk.

The academy symposium was held in the Centre for New Technologies (ZNT) of the Deutsches Museum – a highly appropriate location. The Nano- and Biotechnology Exhibition that opened there in 2009 offers a broad overview of this field. Certain exhibits make deeper digressions into specialized material. Multimedia stands illustrate various ways of looking at the sociopolitical issues and provide visitors with lines of reasoning with which they can find their own answers.

To directly convey the research process, the exhibition encompasses various laboratories, including a hands-on lab where visitors can conduct their own experiments. The Deutsches Museum has been presenting the scientific process live to the public in its Open Research Laboratory since 2005. Nanoresearch is now taking place in the midst of the exhibits, with doctoral students using their instruments and providing answers and explanations to museum visitors. This approach creates a completely new kind of model for young people considering a career in research, giving them the opportunity to meet young scientists.

The researchers, in turn, come to understand that communication must be a natural part of their profession. A study evaluating the Open Research Laboratory highlights the fact that this part of the exhibition is not only viewed very positively by visitors, but is also taken as a stimulus to engage further with the topic of nanotechnology.

Indeed, the innovative concept has already been exported – as Coordinator of the EU's "NanoToTouch"

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project, the Deutsches Museum has supported other science centers and museums in establishing similar Open Research Laboratories in cooperation with local university partners. This new kind of science communication is now being conducted across Europe. This interweaving of dialog and research is a direct response to the demand for more transparency and accessibility in the sciences.

How current research actually happens is being demonstrated here. “Scientists to Touch,” as it were – ready to discuss their own motivation and their own work. In addition, the event forum offers an interdisciplinary platform for lectures, conferences, discussion rounds and public dialog.

Academies and museums are good platforms for hosting public dialog

Science centers and museums are an ideal forum for these kinds of activities. They present information in a neutral environment, offering opportunities for the exchange of ideas and public discourse. That is why the Deutsches Museum has lately been employing numerous techniques in a bid to get visitors actively involved. The Centre for New Technologies makes it clear that not everything feasible is also sensible. Every one of us is called upon to help shape the future together. After all, as the Deutsches Museum sees it, future technologies develop within the context of culture, not isolated in the lab.

The purpose of the “nano” debate can’t be simply to persuade the consumer of the blessings of “nanoproducts.” Rather, manufacturers and communicators must highlight the genuine advantages as against the possible risks and take to heart the concerns and wishes of the consumers. Scientists are challenged to reach out to people and to permit them to share in the scientific world’s knowledge and motivation for finding answers to the future challenges of our society. With the academies and intercommunication platforms such as the Deutsches Museum, we already have a sound foundation for taking this dialog on innovation forward. ◂

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THE BOOK

Wolfgang M. Heckl (ed.), *Nano im Körper, Chancen, Risiken und gesellschaftlicher Dialog zur Nanotechnologie in Medizin, Ernährung und Kosmetik* (German only), 143 pages with illustrations, hardcover, Nova Acta Leopoldina, Neue Folge, vol. 114, no. 392, Halle/Saale 2012, EUR 21.95.