Welcome to Nanotech Germany

Seven reasons why Germany is a strong partner in nanotechnology
Words of greeting

Self-cleaning windows, higher-performance tumour markers or miniature hard discs which can store just as much data as traditional hard discs – nanotechnology opens up manifold new opportunities. Indeed, our everyday lives have become unimaginable without nanotechnology. Whether in sun creams, drinking water treatment plants or automotive paintwork, the tiny particles unfold their enormous potential with just the same degree of efficiency. Nearly all branches of industry profit from developments in nano research. Possible applications can be found in the automotive sector, as well as in mechanical engineering, medical technology, and the chemical, electronic and optical industries. But nanotechnology still has a wealth of innovative potential to exploit. Current prognoses put the 2015 figure for turnover in the nano industry at a trillion euros.

Germany wants to be a major player in the transformation of this key technology. Today, German researchers are right up front in third place in the international league table for patent applications – an excellent starting position to become a pacemaker, shaping tomorrow’s nanotechnology.

In the context of the “Nano Initiative – Action Plan 2010”, the Federal Government has introduced a national funding concept spanning all policy areas. Part of the High-Tech Strategy for Germany, the Nano Initiative contributes to opening up new leading markets, networking business and science, and creating leeway for researchers and entrepreneurs. Our target: to expedite the transformation of ideas into new, marketable products, processes and services so that Germany can become the world’s most research- and innovation-friendly nation by 2020.

With specially created funding programmes, the Federal Government is helping to turn Germany into the leading nano location. In 2008 alone, about 430 million euros were invested by public funding in this future market. Only the USA and Japan invest more state funding in nanotechnology.

Today, more than 750 companies with more than 60,000 employees are already developing, using or selling their nano products. Why don’t you profit from this excellent environment and make the most of your opportunities in Germany?

Dr. Annette Schavan, MP
Federal Minister of Education and Research
German scienti on time. They a ahead of time.
German researchers know all about ground-breaking microscopes. We have the German physicist, Ernst Ruska, to thank for inventing the imaging electron microscope in 1931. He was followed later in the 1930s by Manfred von Ardenne with the invention of the scanning electron microscope, while Gerd Binnig was awarded the Nobel Prize for developing the scanning tunnelling microscope in 1981.

Fine hairs on a leaf, imaged with a German invention, the scanning electron microscope.
Welcome to the research location Germany

Brief account of research and development

Germany is meeting the challenges of globalisation and international competition – and putting its money on education and research. Only inquisitive, learning societies ask the right questions and find the proper answers. Just like economic commitment, being talented and gifted should be made worthwhile for everyone who makes Germany a stronger research location. The Federal Government is determined to provide as much support as possible in this area – and has already been visibly successful.

It’s a fact: the High-Tech Strategy initiated by the Federal Ministry of Education and Research (BMBF) is having an impact. According to a current survey by the Centre for European Economic Research (ZEW), firms that know about the investment programme plan to increase their budgets for research and development “significantly”. Which is quite something, given that the High-Tech Strategy is only a year old.

The Federal Government’s high-tech initiative aims to put Germany at the forefront of tomorrow’s most important markets. Targeted funding is to ensure that new impetus is given to turning research results into products, services and processes much more quickly, and thus creating as many as 1.5 million new jobs. Up to 2009, altogether 15 billion euros of the budget have been earmarked for the investment programme. By 2010, state and private investment in research and development is projected to rise to three per cent of gross domestic product.

The survey shows that companies are counting on a growth rate of more than seven per cent for research and development in comparison with previous years. And the number of employees in companies involved in research and development has increased by 3.5 per cent. Which all goes to show: research and development has a lot going for it in the German economy.

And that’s not all: cutting-edge research is not a prerogative of firms or the numerous universities in Germany; it also takes place at roughly 257 non-university research establishments, employing more than 70,000 staff. These establishments are incorporated in large organisations such as the Max Planck Society, the
Helmholtz Association, the Leibniz Association and the Fraunhofer Society. This is where researchers find optimum conditions matched only at very few other institutions around the world. The Helmholtz Association alone, the largest of the organisations, has about 24,000 staff, 4,500 of whom come from abroad. This is indicative of just how cosmopolitan Germany has become as a location for research. Almost 20,000 foreign researchers are employed by German organisations, most of them in the fields of mathematics and science. The German Academic Exchange Service (DAAD) provides a wealth of services for students, postgraduates and professors who want to live in and do research in Germany. The organisations for investors and companies to contact are the Economic Development Agencies in the 16 Federal States or the umbrella organisation, “Invest in Germany”.

One of the engines for future innovations is undoubtedly nanotechnology. Being a classic cross-cutting technology, nano developments are the starting point for progress in any number of economic sectors. The automotive industry, energy and environment, the health sector – in all these fields lessons learned from nano research set the trend in technological change. And the nano sector creates wealth: according to prognoses, a global market potential of up to a trillion euros in 2015.

Today, Germany is right at the forefront of international nanoscience, particularly as the Federal Government realised the potential of this relatively young field of research very early on and systematically funded its development: since 1998, in BMBF project funding alone, the amount of funds earmarked for nanotechnology has increased more than five-fold. In parallel, centres of competence have been established as supportive infrastructure. Therefore, the German research landscape offers students, academics and companies from home and abroad the best possible pre requisites for success.

Universities – an overview

Almost two million young people study in Germany – about 250,000 of them come from diverse overseas countries. Currently, there are 383 universities, technical universities and universities of applied sciences.

In the field of nanotechnology the universities largely offer courses in the departments of physics, chemistry, material sciences, electrical engineering, computer sciences and engineering sciences. But the departments of mechanical engineering, biology and pharmacology/medicine quite frequently offer lectures and seminars on this cross-discipline technology, too.

So far, independent, interdisciplinary courses in nanotechnology are the exception in university curricula. Essentially, they are limited to “NanoEngineering” at Duisburg-Essen, “Nanostructure Science” at Kassel, “Micro- and Nanostructures” at Saarbrücken, and “Nanostructure Technology” at Würzburg. Erlangen-Nuremberg University offers a course in “Molecular Science” with a focus on nanotechnology. Other science courses in Aachen, Chemnitz and Bielefeld feature additional options in nanotechnology.
Postgraduate courses for prospective nano specialists culminating in a Master of Science degree are offered by Ilmenau University, Jacobs University Bremen and TU Dresden. A distance learning course in nanobiotechnology is available at Kaiserslautern University.

There are fewer courses on offer in nanotechnology at universities of applied sciences (UAS), and those that there are can be found in the departments of electrical engineering/computer sciences, physics, mechanical engineering and materials science. Iserlohn UAS runs a course in “Bio- and Nanotechnology”, and Isny UAS has introduced an “Optical Engineering and Nanotechnologies” option in the “Engineering Physics” course. Postgraduate courses are also on offer at Munich UAS in “Micro- and Nanotechnology”, Nuremberg UAS in “Nano- and Production Technology”, and Zwickau UAS in “Nano- and Surface Technologies”.

**International relations**

Research has long since ceased to respect national borders. In times of globalisation, it is not only industry that is to be found sending its containers around the earth. Science acts globally, too. And there are two forces pushing technological progress ahead: competition on the one hand, and cross-border cooperation on the other.

German nanotechnology is firmly integrated in European research programmes. In the years 2007 to 2013, the European Union (EU) is providing funding totalling more than 50 billion euros for the current Research Framework Programme. Of this, nano research will receive about 3.5 billion euros. By far the largest proportion of this will go to German institutions.

The objective of the EU programme is to concentrate European capacities in the future field of nanosciences. One of its special focus areas is transformation from theoretical knowledge to practical application. Or to put it another way: shortening the route from laboratory to marketable product. Europe-wide research networks are investigating both the social and ecological potential of nanotechnology as well as the possible risks inherent in this new key technology.

Thanks to EU and Federal Research Ministry funding, academic work in nanoscience today is right at the forefront internationally. But not just this: both the number and reputation of firms geared to nano products have grown significantly. At a rough estimate, there are about as many nanotechnology-related companies in the USA as in Europe – approximately half of the firms located in Europe are based in Germany.
Nano-life in Germany

Anyone in Germany researching into the tiniest of particles profits not only from the most generous financial support for nanotechnology in Europe, but also enjoys a high standard of living.

In the “country of poets and thinkers” the great philosophical and literary tradition continues to this day. The world’s largest book fair takes place in Frankfurt am Main, with about 1,800 publishing houses presenting their works every year. And Germany also has a vast music and theatre scene. 135 publicly funded orchestras perform on 80 stages in the land of Bach and Beethoven. Cultural visitors come to Kassel for the “documenta”, one of the most important exhibitions of international modern art worldwide, to Bayreuth for the “Richard-Wagner-Festspiele”, or to Berlin for the International Film Festival, the “Berlinale”.

German countryside is surprisingly varied. There are 15 national parks and 90 natural preservation areas to investigate. Holidays in Germany might mean mountain-eering in the Alps, walking in the legendary Black Forest or along the Wine Trail through the Palatinate or Baden, or simply relaxing on the white beaches of the Baltic or North Sea. And sport is a major feature, too. No other country has as many sports clubs as Germany – roughly 90,000, all told. In the big cities, major sporting events like inline skating or marathons take place regularly.

The society researchers experience in Germany is multicultural and cosmopolitan: more than seven million foreigners originating from all over the world live here. Duesseldorf at the Rhine River is the European centre Japanese companies have chosen – there are Japanese restaurants, book shops and schools. In Hamburg, the Portuguese feel at home, and Berlin is the favourite adopted home town for Turkish immigrants in Germany. An estimated 25,000 Chinese study at German universities across the country, while amongst Polish students, Viadrina European University in Frankfurt/Oder is particularly popular.

A wealth of societies guarantee a lively exchange between cultures, and indeed religions. Religious freedom is enshrined in the Basic Law – whether in churches, mosques, synagogues or temples: every belief has a home here. Altogether, there are more than 120 different religious affiliations in Germany. And children learn to get along with one another at an early age – in playgrounds, day-care centres, or at school. In some cases, the first foreign language is introduced at kindergarten; other foreign languages follow at school. There are already 600 schools offering bilingual teaching – usually in English and German. But Spanish, Russian, French and Chinese can be learnt, too.

In addition to economic aspects, this kind of cosmopolitanism is certainly one of the reasons why more than 22,000 companies with foreign participation have successfully established themselves in Germany.

Investment also thrives on security. Germany is a stable and transparent constitutional state – its administration and judiciary are a model for many other countries. Bureaucracy, antiquated laws and regulations are being radically reformed, of course, with proverbial German thoroughness: the state of Baden-Württemberg, for example, dispensed with half its administrative regulations at one fell swoop. By comparison with the rest of the world, Germany, with its stable, democratic, constitutional state, is one of the safest countries of all – in which to live, to invest and, of course, to do research.
The signature on one of many approved research proposals.

In the coming year, private enterprise will be investing 50 billion euros in German research and development for the first time. The Federal Government is going to spend 9.4 billion euros in 2008. Some of this will flow into the “Nano Initiative – Action Plan 2010” and will ensure that research funding ends up where it is really needed.
No country in Europe spends so much money on things nobody has ever seen.
Innovation knows no boundaries – Nanotechnology in Germany

Our strengths and skills

“Skilled in Germany” – a byword for excellently trained German personnel who are gaining recognition throughout the world. Together with its varied and differentiated research landscape, this is one of the ways in which Germany is managing to score in international competition. And, most of all, the country is backing the next generation of skilled workers and academics – the experts of tomorrow and the day after.

Qualified personnel, extensive research, and intelligent promotion of young people benefit future key technologies, too. In the nano field in particular, there is a lot of potential for Germany to blossom in the coming years. And it’s going to do so. Whether we are talking about highly selective cancer therapies, novel sun protection, or miniscule data storage – in nanotechnology, innovation knows no boundaries. Today, there are already 750 companies developing, using or distributing their products in Germany and providing employment for more than 60,000 people – with an upward trend.

Apart from universities and industry, the leading scientific institutes and establishments are also involved in basic research – most of the nano patents in Europe originate in Germany. And increasing student numbers in nanoscience fields prove the point: ever more young people are becoming interested in jobs in the nano sector. Well-trained, skilled personnel will guarantee a competitive edge in future, too. To achieve this, the Federal Government is providing extensive funding in the context of programmes such as “NanoFutur”, which promotes the creation of independent junior research groups.

Internationally, Germany already ranks among the best: both in relation to research spending and patent applications Germany comes in third place, only outstripped by the USA and Japan. In the rankings for academic publications, the
Federal Republic is the best European country, coming in fourth overall after China. To expedite the process of turning good ideas into successful products, in its Nano Initiative the Federal Government is investing in a package of measures – and setting the course for the future of nanotechnology in Germany in the “Action Plan 2010”. This will involve all our well-known strengths. Alongside excellent basic research, innovation-friendly industry, and well-trained young personnel, Germany can rely on its internationally oriented technology networks and centres of competence – for yet more new, cutting-edge achievements “made in Germany”.

Basic research

Whether you think of energy-efficient processing systems for drinking water, secure data transmission systems, or food packaging with freshness sensors – the broad spectrum of tomorrow’s innovations in nanotechnology are, mostly, the result of painstaking research work in Germany. Prestigious scientific institutions produce ever more new knowledge and are increasingly working hand in hand with industry to achieve concrete application targets. Together with the Leibniz and the Helmholtz Associations, the institutes of the Max Planck Society and the research institutes of the Fraunhofer-Gesellschaft are amongst the leading establishments in their fields worldwide. However, at nearly all German universities with a technical focus experts are addressing nanotechnology issues. All in all, Germany has very exceptional research potential to offer – which ought to be of interest to guests from abroad as well.

Nanotechnology in practice

The sooner a good idea makes the transition from laboratory scale to ground-breaking product the better. In this area, German industry already has the vital know-how to venture into new dimensions in the nano sector. While large corporate groups tend to work on systems solutions with high sales expectancy, companies and engineers in small and medium-sized enterprises are particularly involved in production, analysis and device technologies. In this area, the perennial world export champion is well-placed, both with regard to knowledge and infrastructure – it is not for nothing that Germany set its sights on industry-oriented issues and accompanying measures at a very early stage. This includes targeting innovation-friendly small and medium-sized enterprises and start-ups for promotion as well as strategic collaborative projects at the interface of research and industry – to engender yet more new developments for tomorrow’s markets.
The young nano generation

Wanted: skilled personnel with thorough, interdisciplinary knowledge and abilities. This is the reason why Germany needs and promotes its younger generation in particular, because expertise is the key to economic success. And innovation often begins with shrewd promotion of young talent. Targeted support already kicks in at school where nano topics and experimental learning arouse the curiosity of even the very young. In addition to this, the Federal Government’s measures include science competitions in the nano field as well as information aimed at young people, telling them about promising new fields of employment and new educational opportunities. These are coordinated with the needs of industry. Fairs, workshops and surveys also help to identify new qualification trends and integrate them into tailored educational opportunities in higher and vocational education. “Catch them early”, so to speak.

Networks

Success is usually a question of good teamwork and optimum communications. Thus, as a further measure in addition to promoting research, industry and young people, the Federal Government is pooling specialised knowledge in nanotechnology and also accelerating innovative processes by strategic information exchange. A network of so-called centres of competence, currently comprising nearly 500 participants and probably unique in the world, links universities, research institutes, companies, financial service providers, consultants and associations. These networks work in different subject areas both at the national level and in regional clusters. Apart from trends and current developments, these centres also focus on training and further education. The interdisciplinary consortium “AgeNT-D” will be taking over coordination of the nano centres. A number of largely independent university networks complement the excellence teams at the local level.

The Federal Government’s High-Tech Strategy and nano initiative

Germany would like to become one of the most research- and innovation-friendly nations in the world. From biotechnology to communications, from aviation and aerospace, to microsystems technology: the Federal Government’s High-Tech Strategy is the roadmap leading to the forefront of tomorrow’s most important markets. To this end, research spending is scheduled to reach three per cent of gross domestic product by 2010.

Being a cross-sectional technology, the nano sector enjoys a special status in this context: on the basis of the “Nano Initiative – Action Plan 2010”, the Federal Government wants, above all, to improve the interface between basic research and rapid implementation. Comprehensive measures are on the drawing board which should help to improve the exploitation of nanotechnology in Germany – and meet the new challenges. Eight ministries, each with its own nano representative, have put together the package of actions.
There’s lots to be done: apart from expediting the process from idea to product, in the future ever more new sectors and companies are to be introduced to the nano field. Branch-level industrial dialogue between representatives from politics, the economy and associations helps to find areas of application for economic areas not catered for so far. As well as dialogue, the action plan also promotes so-called leading innovations which the Federal Government hopes will generate a high degree of growth and employment. In the field of lighting technology, these include the “NanoLux” project and the OLED Initiative: whereas NanoLux is essentially preparing the way for energy-efficient light-emitting devices in the automotive industry, the OLED Initiative wants to create the technological basis for organic light-emitting devices as a cheap, large-scale lighting option.

Small and medium-sized enterprises in particular often prove to be especially innovation-friendly. They receive support from the action plan by means of funding and structural measures, such as the “NanoChance” programme for start-ups. And the Federal Government is also pooling its activities with regard to potential risks. A steering group under the direction of the Federal Ministry for the Environment is assessing the chances and risks involved in dealing with nanomaterials. In the context of nano dialogue, experts from industry and society evaluate dangers as well as perspectives and also discuss tomorrow’s research needs – to engender yet more discoveries in the land of ideas.

Dexterity required: Start-ups involving young nanoscientists – here the view through a transparent, conductive film – are the centrepiece of the NanoChance funding programme.
German engine work precisely, millimetre. Those...
Zinc oxide nanorods, wet-chemically prepared on sapphire. Intended for application as novel electrodes in ultrathin solar cells, developed at the Helmholtz-Centre Berlin for Materials and Energy.

The new benchmark for German precision is the nanometre, because research into tiny things plays a big role in Germany. This is evidenced by the invention of nanorods made of zinc oxide at the Helmholtz-Centre Berlin for Materials and Energy. Here, the large number and close proximity of universities, specialised institutes, and innovative firms offers optimum conditions for research and development in nanotechnology-based ideas.
The most important research organisations

“There’s plenty of room at the bottom,” claimed the American physicist and Nobel Prize winner, Richard Phillips Feynman, in December 1959. This lecture is considered to be the founding document of nanoscience. In Germany, many non-university research establishments are busy exploring Feynman’s so-called “room at the bottom”. They are trying to identify the potential and options opened up by the nano world and harness them for mankind. We should like to introduce you to the most important research organisations.
Polymaths are thin on the ground nowadays. The sheer volume of knowledge is too vast for one single person to cope with. Three hundred years ago, things were different. One of the people who demonstrates this best is Gottfried Wilhelm Leibniz (1646–1716) who was a groundbreaking political scientist, mathematician, historian, philosopher and poet. The French Enlightenment thinker, Denis Diderot, said of him that he alone had brought Germany as much glory as “Plato, Aristotle and Archimedes together”.

Today, an entire science organisation is necessary to achieve what a single polymath could manage in the 17th century. The Leibniz Association (WGL) carries over the standards of its namesake into the present day. Founded in the 1990s, the organisation today combines 83 research institutions, addressing issues of importance to society as a whole. They provide infrastructure for science and research as well as research-based services – liaison, consultancy, transfer – for the public, policy makers, academia and business.

Leibniz researchers are active in the fields of science, engineering and environmental science as well as economics, social science, infrastructure research and the humanities.

The nano sector plays an important role in the portfolio of the Leibniz research cluster: WGL institutes carry out basic research and close-to-market research in nanotechnology. Focus areas can be found in nanomaterials research – significant actors include the Institute for New Materials (INM, Saarbrücken), Solid State and Materials Research (IFW, Dresden), and Polymer Research (IPF, Dresden). A second focus area is surface processing, at the Institute for Surface Modification (IOM, Leipzig) and the Research Centre Rossendorf (FZR), for example. Basic research in solid state electronics is undertaken by the Paul Drude Institute (PDI) and application oriented work in optoelectronics and high frequency technology is performed at the Ferdinand Braun Institut für Höchstfrequenztechnik (FBH), both in Berlin.

New benchmarks: fully automatic wafer steppers, such as this one at the Ferdinand Braun Institute, pass light onto semiconductor wafers coated with photoresist. Their high precision makes it possible to produce circuits on the micro- and nanometre scale.
Helmholtz-Centre Berlin for Materials and Energy (HGF)

Hermann von Helmholtz (1821–1894) possessed one characteristic every researcher can do with: boundless curiosity. His name stands for the whole palette of scientific research. He was an exponent of science as a bridge builder between medicine, physics and chemistry. His groundbreaking research and developments linked together theory, experimentation and practical application. So there are good reasons why the Helmholtz Association – Germany’s largest science organisation – bears his name.

Fifteen scientific-technical and medical-biological research centres are combined under the umbrella of the Helmholtz Association. It is their task to pursue long-term research goals for society. Helmholtz scientists investigate the basis of human existence – with the objective of preserving and improving it. To this end, they identify and address the major, pressing issues thrown up by society, science and industry by means of cutting-edge, strategic research programmes in six areas of research: energy, earth and environment, health, key technologies, structure of matter, and transport and space.

In the nanosciences, HGF focuses on material-related issues and nanoelectronics. In this context, outstanding work is done by the two research centres in Karlsruhe (FZK) and Jülich (FZJ). However, research and development in nanomaterials and layer systems also takes place at the Research Centre Geesthacht (GKSS) and the Helmholtz-Centre Berlin for Materials and Energy.

The Max Planck Society (MPG)

Entropy, radiation law and thermodynamics – these are all concepts closely associated with Max Karl Ernst Ludwig Planck. The physicist, who was born in Kiel in 1858 and died in Göttingen in 1947, was one of the most important scientists of his day. His epoch-making lectures on quantum theory redefined the physical view of the world of 1900. He was awarded the Nobel Prize for this research in 1918. One of his mottos was “insight must precede application”.

This is the guiding principle the Max Planck Society (MPG), the successor organisation to the Kaiser Wilhelm Society (KWG), chose to adopt when it was founded in 1948. It is the holding society for 78 Max Planck institutes and research establishments.

The Max Planck Society essentially performs basic research in natural science, social science and the humanities. It works together with university institutions – but maintains its independence. It concentrates on transdisciplinary research objectives which other research establishments involved in basic research are unable to take on.

The work of Max Planck institutes (MPI) produces significant basic insights into new approaches to nanotechnological research. For years, the Stuttgart institutes for Solid State Research and Metals Research and the MPI of Microstructure Physics in Halle, for instance, have been active in the fields of nanomaterials, supra-molecular systems, characterisation procedures and new...
functionalities. Globally recognised R&D results have also followed from the work of the institutes for Polymer Research (Mainz), Colloids and Interfaces (Golm), Biochemistry (Munich-Martinsried), Coal Research (Mülheim), Iron Research (Düsseldorf), as well as from the Fritz Haber Institute (Berlin), of which one of the “newest” Nobel Prize winners, the chemist Prof. Gerhard Ertl, was once director.

The Fraunhofer-Gesellschaft

He was a scientist who always had an eye to the practical application of his research findings in innovative products. In optics, in particular, Joseph von Fraunhofer (1787–1826) set new standards. He was equally successful as a researcher, an inventor and a businessman. And this is one of the reasons why he was chosen as the role model and eponym of today’s Fraunhofer-Gesellschaft.

Established in 1949, today Fraunhofer is the leading organisation for applied research in Europe. It currently runs more than 80 research establishments, of which 56 are institutes located throughout Germany. 12,500 staff, largely science- or engineering-trained, are employed by the FhG. Their major common objective is to carry out application-oriented research of immediate use to companies and of benefit to society. Their main clients are thus industrial and service companies and public authorities.

Today, nanotechnological projects with concrete application targets are being undertaken by numerous Fraunhofer institutes, working together with industry. As a result of many years’ funding by the BMBF, layers and surfaces have become one focus of research. In these fields, the institutes for Material and Beam Technology (IWS, Dresden), Silicate Research (ISC, Würzburg), Applied Optics and Fine Mechanics (IOF, Jena), and Interface Engineering and Biotechnology (IGB, Stuttgart) are particularly active. Priority is given to nanomaterials research at the institutes for Manufacturing Technology and Applied Materials (IFAM, Bremen), and Chemical Technology (ICT, Pfinztal). Insights at the intersection of microtechnology and nanotechnology are the stuff of the institutes for Silicon Technology (IST, Itzehoe) and Production Technology (IFT, Aachen); the relationship to nanobiotechnology is of central importance to the Institute of Biomedical Engineering (IBMT, St. Ingbert). The Institute for Solar Energy Systems (ISE, Freiburg) investigates the contribution nanotechnology can make to energy production. Most of these institutes are involved in the “Fraunhofer Nanotechnology Alliance”.

High utility value: nanoparticles make surfaces more resistant. The manufacture of interference layers is a good example of close cooperation between research and industry.
All the really big fit into a single m
This 100-nanometre-sized piece of metal is formed using a mini anvil and a mini hammer. A future technique which could be applied to producing tiny trephines for unblocking arteries. As the nanoblock proves: size tells us nothing about the hugeness of an idea.
Terrific variety – Nanotechnology in practice

The major technologies

From medicine to the optical industry, from chemistry to environmental technology: ever more German companies are investing in nano ideas. There are now more than 500 small and medium-sized enterprises and numerous start-up companies as well as large corporate groups where engineers and other experts are busy translating new knowledge and concepts into high-performance products and services. Cheap and more efficient solar cells, sustained-release drug delivery carriers, or cost-effective production of drinking water are just a few of the many innovative examples of future applications. The huge number of suppliers also plays a decisive role, for instance in the automotive industry. Good ideas have frequently turned into success stories, with start-ups becoming publicly traded companies or even world leaders in their field. In the following, important technologies in the nano sector exemplify a new chapter in German economic and scientific success.

Nanoanalytics

To make the tiniest particles as visible as possible and be able to analyse them – these are the tasks of nanoanalytics. Its performance dictates the pace of development in industry and research. “Nanometre-sized” devices can, after all, only usually be manufactured accurately if the analysis methods used in quality control also work on the nanoscale.

Nanoanalysis methods make it possible to examine a vast number of properties. With regard to technical issues, the most important are 3D structuring as well as knowledge about the electronic, magnetic, mechanical, optical and chemical properties of nanomaterials. The Omicron NanoTechnology company, for example, uses a combination of modern and traditional microscopic procedures to make materials visible on the atomic scale. With the aid of this combined method it is also possible to deduce information on the chemical composition of the samples and extend the field of vision on the materials being examined.
The high-performance time-of-flight secondary ion mass spectrometer (TOF-SIMS), produced by the ION-TOF company, allows precise analysis of the chemistry of surfaces in particular. Other manufacturers of nanoanalysis systems in Germany are for example, Carl Zeiss, Leica, Nanofokus, Fries Research & Technology, WiTec, JPK, and Surface Imaging Systems.

Nanobiotechnology

Nanobiotechnology can save lives. Already today, innovations in medicine and the so-called life sciences make it possible to target future use of pharmaceuticals and largely avoid side effects. The tiniest pharmaceutical carriers help to administer active ingredients precisely. Sustained-release drug delivery carriers for diabetes and neurodermatitis, for example, just like early diagnosis methods and less aggressive cancer therapies, improve the quality of life of those affected. Capsulation NanoScience, for instance, produces nanocapsules which, depending on the application, can be used as miniscule vehicles for active ingredients. The world’s first nano cancer therapy has been developed by Magforce. “Nanotechnology is the future of medicine,” Marco Beckmann, chief executive officer of Nanostart AG and investor in Magforce, emphasises. The company is currently developing a new cancer therapy based on magnetic nanoparticles.

Nanomaterials

Magnetism, optical properties or chemical reactivity – the tinier the particles are, the better these typical qualities come to the fore. In the world of nanomaterials in Germany, it is not just high quality that counts but high manufacturing performance, too. Highly developed nanoparticles and nanoscale powders are the basis for novel materials like transparent ceramics or filter systems. They are used in many branches of industry, for manufacturing enzymes in pharmaceutical research, for instance, for filtering polluted drinking water, or for ceramic coatings. In this context, ItN Nanovation in Saarbrücken has one of the most modern production plants for technical ceramics in the entire world. Along with many others, companies like Thyssen Krupp Stainless and Erlus Building Materials are engaged in producing or processing materials in the nanometre range. Bayer MaterialScience is active in the field of nanotubes with a view to mass-producing so-called “multi-talents”. By creating the R&D department Nanotronics, Evonik Degussa has developed a centre for innovative products based on nanomaterials.
Nanooptics

Research, development and production in the field of nanooptics are carried out at more than a hundred locations in Germany. No less than ten large corporate groups work with light in the nanospectral field, including Leica, Osram and Philips. Choose-your-own-colour, energy-saving lighting systems, seriously non-scratch ophthalmic glass, photonic crystals and optical nanoresolution microscopy are all examples of today’s and tomorrow’s applications. Plasma technology, which is important for the production of microchips and solar cells, also functions in nanometres. Thus, thanks to the relevant hardware, the Roth & Rau company offers a ready to use concept for the fully-automated mass production of solar cells. And at Carl Zeiss SMT information is transmitted, just like a slide projection, by light beam in the nanometre range onto silicon surfaces in order to produce ever more efficient data storage.

Nanoelectronics

Consumer electronics, semiconductors or high-performance servers – the world of nanoelectronics is as diversified as the multiplicity of branches and applications. Ever higher performance, ever smaller components and ever less costs are the challenges German companies like Qimonda, Siemens, Bosch and AMD are facing. Semiconductor technology, in which Germany plays a leading role, also has a special function in this context. For years, Professor Peter Grünberg worked at the optics interface in the field of nanooptoelectronics, at the Jülich Research Centre. In 1988, he discovered the GMR effect which occurs when a non-magnetic layer only a few atomic layers thick is placed between two ferromagnetic layers such as iron or cobalt. Today, this so-called spacer, that functions as a highly efficient performance enhancer, is an integral part of every computer hard disk and makes it possible to maximise data storage capacity. Together with his French colleague, Albert Fert, Professor Grünberg was awarded the 2007 Nobel Prize in Physics for this discovery in the nano field.

Filter systems on the nanoscale: a nanomembrane made of high-performance materials already used in aeronautics and aerospace will in future withhold bacteria and micro-organisms from the air or polluted water.
Nanochemistry

Germany is considered to be one of the leading countries in research and development in chemistry. This is also true of cross-industry technology in the field of nanochemistry, whereby the optical industry is one of those to profit from new methods of surface coating. Nearly all major chemical companies are also involved in the production of nanoscale materials. The company Sustech, for example, a subsidiary of Henkel, develops innovative substances such as adhesives on a chemical basis. However, further development of lithium-ion batteries is also a topic of industrial chemical research. Li-Tec and Evonik-Degussa are two examples of groundbreaking nanotechnology: together they are developing and producing an extremely reliable, sustainable new generation of batteries for future use as large batteries in electric and hybrid vehicles. According to the managing director of Li-Tec, Dr Andreas Gutsch, “Strategic partnerships are decisive in the contest for innovations.” BASF also participates in innovation alliances. Together with other partners in the chemical industry it is, for example, developing nanochemical production processes along the value chain.
An eyelash belonging to Dr Max Lemme

Dr Max Lemme worked for the micro- and optical electronics company, AMO. In his project, “ALEGRA”, he was investigating the alternative semiconductor, graphene. This nanometre-thin carbon compound could revolutionise tomorrow’s electronics, just as silicon did in the past. The Federal Government is supporting the project in the context of “NanoFutura”, promoting the next generation.
Our younger generation knows a lot about tiny things.
Award candidates – Germany’s next nano generation

Preparing researchers for research

The era of discovery is over, it is claimed. That’s not true. There are still a lot of empty spaces on the map of the nanocosmos in particular, and pioneers are wanted to measure these areas. The world after the decimal point offers generations of scientists thousands of opportunities to give free rein to their curiosity and thirst for adventure – with excellent prospects for their personal future into the bargain.

Germany’s nanotechnology is inspiring a spirit of discovery – amongst young researchers as well as students at school and university. One example: in order to continue developing our attractiveness as a research location, which is already excellent by international standards, the BMBF is running an international NanoFutur competition to attract junior researchers from every conceivable country. They then have the opportunity to spend five years building up a research group – largely under their own direction. The first 29 independent junior research groups have already been established.

Eight of the young academics promoted have already been appointed to professorships.

But efforts to encourage the new nano generation go well beyond just recruiting new talents. As tomorrow’s researchers, developers and entrepreneurs, it will be precisely the very youngest generations who will push back the borders of the possible in the nanocosmos. And that is why we introduce students in secondary and higher education to the topic at an early stage. There are many ways of presenting the fascination of nanotechnology: in the form of initial tentative steps in experimentation at school level, or with the help of multimedia presentation materials: interactive websites and teaching material introducing nanotechnology are already being used.

Whether in academia or industry – the need for personnel well qualified in nanotechnology is going to increase significantly. That’s why we have to develop educational programmes now that are
precisely tailored to future demands. The Federal Government has thus commissioned a number of studies to sound out the options in higher education and training in nanotechnology. Universities and universities of applied sciences in particular offer appropriate qualifications in courses geared to nanotechnology with a specifically interdisciplinary approach — usually a combination of engineering and natural sciences.

When exactly the first nanochemist or nanooptician will complete his or her training in the dual system of vocational education is as yet unclear — but the first contours of the relevant job descriptions are clearly visible on the horizon today. Qualification profiles are already being drawn up, not only for the fields mentioned, but also for nanonanalytics, nanobiotechnology, nanoelectronics and nanomaterials, containing job descriptions, operational areas and points of contact with existing occupations, as well as specifying the required expertise.

School, training or study: we are setting the wheels in motion to awaken young people’s enthusiasm for the nanocosmos. In the following, you will be given some insights into the everyday life of young nanoscientists in Germany — and find further facts and figures on the subject of the next nano generation.

Selected universities and their research focus

On the international market, successful nano companies are in competition for the best developments, best products and excellent personnel. By 2015, the market volume for nanotechnology is predicted to reach over a trillion euros worldwide — which means, among other things, new jobs. Even today, between 50,000 and 100,000 jobs are directly or indirectly dependent on nanotechnology. In the coming years, the around 750 companies active in nanotechnology in Germany are expecting to increase their workforce by 20 to 50 per cent.

• Since 2002, a “NanoClub” has been in existence at the Technical University, RWTH Aachen, with the objective of networking the RWTH’s interdisciplinary research activities in the field of nanosciences and nanotechnology. The “NanoClub” bundles the widely spread expertise of the various departments. It also provides an effective platform for regional, state, federal and European activities. The “NanoClub” cooperates with participants from industry, the Jülich Research Centre and numerous Fraunhofer institutes.

• At the excellence university Karlsruhe, more than 200 scientists and technical staff from the departments of physics, chemistry, electrical engineering and information technology, chemical process engineering and from the Institute for Nanotechnology (INT) work at the Centre for Functional Nanostructures on the fundamental principles of new electronic and photonic devices. The centre was established in 2001 and is funded to the tune of 7.5 million euros annually for a projected period of twelve years by the German Research Foundation (DFG), the state of Baden-Württemberg and Karlsruhe University.

• The Institute of Solid State Physics at Berlin’s University of Technology (TU Berlin) is one of the largest training centres for semiconductor technology in Germany. In 2004, the Centre of Nanophotonics was founded, enabling the development and processing of novel complex optoelectronic devices based on nanostructures. The project received a total of approx. 5.4 million euros in funding. This was TU Berlin’s way of reacting to
extremely high industrial demand for qualified personnel in the fields of semiconductor-based technologies and devices. The institute’s training, research and development work has lead to the foundation of a whole series of successful spin-off companies.

- The Centre for Nanotechnology, CeNTech, at Münster University aims to initiate spin-offs in the field of nanotechnology and support companies in the nano sector. CeNTech is also involved in extending training and further training measures. By organising specialist events like the congress fair NanoBioEurope, as well as special workshops, both researchers and start-up entrepreneurs are offered an international forum for debate and initiating new collaborations and alliances.

- The Centre for NanoScience (CeNS) at Munich University (LMU) promotes interdisciplinary research and teaching in fields dealing with objects and functions on the nanometre scale. CeNS promotes cooperation between different scientific disciplines by pooling knowledge, technologies, facilities and resources, and also invigorates interdisciplinary training by means of joint teaching modules and workshops. The centre endeavours to establish collaboration with industry.

- The Centre for Nanointegration at the University of Duisburg (CeNIDE) pulls together and promotes cooperation in nanotechnology among the university’s departments of physics, chemistry and engineering as well as external partners in research and industry. The centre offers unique fabrication facilities for nanoscale materials, and a newly established “Nanoengineering” study programme.
Smaller and brighter: young German scientist leads research in nanophotonic structures and materials

Dr Cedrik Meier, 35, is leading a team of researchers at the University of Paderborn who are working in the area of nanophotonic materials. The group’s goal is to discover new effects made possible by manipulating light waves and use those effects to create smarter, better and smaller electronic components. “If you continue to make opto-electronic components smaller, you will eventually be able to create electronic components that are about the size of waves of light,” said Meier.

In 2006, while at the University of Duisburg-Essen, Meier was awarded the BMBF’s prestigious “NanoFutur” prize for his project “NanoPhOx–Nanophotonics with Oxides”. The goal was to use nanotechnology and zinc oxide to manipulate the properties of light and create new possibilities for developing electronic components for optical electronics. The prize came with 1.7 million euros to be used over five years. Part of the funding went to develop a team of young scientist working in this area.

“The prize proved the trust I earned from other scientists. It’s a great privilege to design and conduct my own experiments freely. The prize money gives me and my team a great deal of independence,” said Meier.

Meier earned a master’s degree in applied solid-state physics at the University of Bochum in 1998. At the same university in 2001, he was also awarded a doctorate for his work on the fabrication of nanostructured semiconductor devices. In 2003, the DFG awarded Meier a research fellowship for two years of post-doctoral study at the California NanoSystems Institute of the University of California in Santa Barbara.

Though not the focus of his work, some aspects of Meier’s research may even help the environment. For instance, as researchers develop smaller, more defined sources of light, the technology may be used to create energy-efficient lighting.

Meier is excited about the opportunities his work creates and the freedom he can explore in Germany: “I was trained as a semiconductor physicist, and over the years I studied how new electronic components developed. For me, it’s exciting to see the move from electronic components that operate with electricity to those that work with light. This opens up all kinds of possibilities, particularly in communications technology. There are all kinds of ways to connect semiconductor technology with modern photonic and optical technology.”

Professor Meier, a recipient of the NanoFutur Preis, is leading a team that aims to discover new effects made possible by manipulating light waves. They want to use those effects to create smarter, better and smaller electronic components.
German scientists and collaborators are not scientists. They are entrepreneurs.
For years, the Federal Government has been investing in networks of competence involving industry and academia. This is because a convergence of various disciplines, institutions and partners is essential for the success of nanotechnology-based ideas and products.
Technology plus transfer – Networks and centres of competence

Bundling expertise

Together we’re strong – this could be the slogan of networks of competence. Bundling strengths, exchanging information, arranging cooperation, providing and maintaining support, promoting the next generation: these are some of the aims of the networks to which companies, research establishments and, indeed, universities belong. If everyone communicates and cooperates closely, this leads to synergy effects which, in their turn, mean better research, very good performance, and market-ready products.

With its initiative, “Networks of Competence Germany”, the Federal Government is supporting the most effective networks of competence in Germany. Networks of competence are clusters of innovation in a particular field that are concentrated in one region but operate nationally. They are capable of producing technological innovations with particularly high added-value potential.

Currently, there are nine centres of competence in the field of nanotechnology in Germany working along the value-added chain. In addition, a number of clusters have established themselves which bundle their activities nationally, regionally or even locally. Some of the largest are:

Nanotechnology Centre of Competence “Ultrathin Functional Films”

Saxony region

Ultrathin films are often a key element in nanotechnology. Their field of use ranges from microelectronics and optics via medicine to wear protection. In Saxony, 51 companies, ten university institutes, 22 research establishments and five associations have bundled their know-how and got together to form a network. They have one common goal: to exploit industrial application potential. The Fraunhofer Institute for Material and Beam Technology (IWS) Dresden coordinates this network which was chosen as the National Centre of Competence for the field of ultrathin functional films by the Federal Ministry of Research.
CC-NanoChem / NanoBioNet – Networks for Chemical Nanotechnology / Nanobiotechnology

Saarbrücken/Saarpfalz region

The CC-NanoChem centre of excellence started up in 1998, specialising in chemical nanotechnology. This is one of the key areas destined to influence decisively the products and materials of the 21st century, as well as the manufacturing and processing technologies. New processes make it possible to shape materials precisely at the level of atoms and molecules: the physical properties of materials can be tailored for change, for example. The NanoBioNet network followed in 2002. It focuses on nanobiotechnology – the interface between nanostructure science and biology – and works together closely with the Nano+Bio Centre at the TU in Kaiserslautern. Both networks offer their members a forum for exchange between universities, research centres, small, medium-sized and large enterprises, as well as consultants and venture capitalists. And there is expert assistance for start-ups, too. Even school students can come here to experience the things nanotechnology can do. Experimental kits and nano nights familiarise young people with this future technology.

ENNaB – Excellence Network NanoBioTechnology

Munich region

Gifted junior researchers and industrial enterprises working in the nano- and biotechnology fields are the groups targeted by ENNaB – Excellence Network NanoBioTechnology. The network understands its role as the link between university and industry – between basic research and industrial application. Its aims include training competent research and management personnel for universities and industry, and thus creating a solid basis for the commercial implementation of new, innovative applications in the field of nanobiotechnology.

CCN – Competence Center for Nanoanalytics

Münster region

The main tasks of the network include the continued development of nanoanalytic measuring methods, their adaptation to technological demands and their standardisation. Special raster scan techniques are one of the network’s methodological focus areas.
IVAM Microtechnology Network

Ruhr region

IVAM is an international network bundling microtechnology, nanotechnology and new materials. The aim of the association is to make technological developments in this area known to a broader public and to market them. The network essentially helps small and medium-sized enterprises to bring innovative technologies and products to market and thus stake their claim in international competition. The IVAM network currently comprises about 250 companies, institutes and partners.

HanseNanoTec Competence Centre

Hamburg region

The HanseNanoTec competence centre is the point of contact for all researchers, entrepreneurs, financial service providers and funding organisations in the Hamburg region working in the field of nanotechnology. It bundles the Hanseatic city’s expertise in this sector and initiates and promotes cooperation with supraregional and international partners. The objective is to optimise efficient acquisition of basic insights and swift transformation of nanotechnology knowledge into products, manufacturing processes and services.

UPOB – Competence Centre Ultraprecise Surface Figuring

Brunswick region

The Brunswick nanotechnology competence centre is a cluster amalgamating production technologies, machines and machine components, metrology, sensor technology and materials. As the respective methods used differ significantly, the network is divided up into four core areas: mechanical/chemical processing, ion beam and plasma processing, optical processing and related topics, and characterisation of surfaces. This is a perfect way of bundling capabilities and presenting them to the public.

A copper crystal on the nanometre scale: characterisation of surfaces is one of the four core areas at the Brunswick competence centre.
Findings from research into optics and optoelectronics are being translated into new applications ever more quickly – thanks to the transfer of know-how between universities, research centres and companies.

**NanoMat**

Karlsruhe region

Nanotechnology materials are the focus of NanoMat. They coordinate research projects on “the synthesis and study of nanostructured metals and ceramics and the functions resulting from their nanoscale nature”. Three research centres of the Helmholtz Association, ten universities with natural science and engineering departments, a Max Planck institute, a Leibniz institute, a Polish Academy of Sciences institute, three Fraunhofer institutes, the Society for Chemical Engineering and Biotechnology (DECHEMA), and four large corporate groups participate in the network.

**NanOp – Competence Centre for the Application of Nanostructures in Optoelectronics**

Berlin/Brandenburg region

The NanOp centre of competence, a network comprising universities, research establishments for applied and basic research, industrial enterprises, and banks as well as venture capital firms, is engaged in research and development in nanotechnologies for application in new and revolutionary products based on nanooptoelectronics. Close cooperation between all the partners involved in the network and fast transfer of know-how produce synergy effects.
Nanoparticles. We have to assess the related risks responsibly in order to utilise nanotechnology’s potential to the full.

The Federal Government’s “Nano Initiative – Action Plan 2010” provides for a responsible approach to handling the opportunities and risks of nanotechnology. By 2009, eight million euros are to be invested in understanding and controlling the toxic potential of nanomaterials, because this is the only way of exploiting opportunities safely.
There are risks inherent in nanotechnology. The major one: not to exploit its potential.
Acting responsibly – Opportunities and risks of nanotechnology

Researching responsibly

Progress opens up enormous opportunities but also has inherent dangers. The nanotechnology future is not totally risk-free, either. It is important not to play down these risks without actually exaggerating them. What is certainly clear is that we have to ensure that we can calculate – and thus control – the toxic potential undeniably present in nanomaterials. An objective and open attitude is the way to a safe future.

In the future field of nano, the Federal Government tries to engage in dialogue with the public. The “Nano Initiative – Action Plan 2010”, which was started in 2006, saw the birth of the first unified, cross-departmental approach which also emphasises responsible and secure handling of nanomaterials. At the heart of this initiative is a cluster combining the projects NanoCare, INOS and TRACER: the Federal Government, academia and industry are developing new, standardised procedures to improve assessment of the danger potential of nanoparticles, and involving the public, too. Funding up to 2009 totals approximately eight million euros.

- The NanoCare project focuses on examining primary particles and agglomerates and the way they behave in biological media and systems. State-of-the-art analytical methods from the most diverse institutes are used to characterise the nanoparticles.

- The INOS project is geared to developing methods based on in vitro testing to evaluate the danger potential of engineered nanoparticles. The hazard analysis is based on a comprehensive investigation of the behaviour of nanoparticles in various cell culture media and the changes they undergo.

- Carbon nanotubes (CNT) and carbon nanofibres (CNF) are already considered to be some of the 21st century’s key materials. In central fields of technology, such as chemistry, the automotive industry, aeronautics and aerospace, they are achieving technological breakthroughs. Emerging industrial manufacture of carbon nanotubes is likely to open up other fields of technology and pave the way for a multitude of mass applications. The objective of the TRACER project is to draw up recommendations for handling potential end products during manufacture, processing and use.
Dealing so openly with the opportunities and risks inherent in these minuscule particles is creating a positive climate in Germany which favours nanotechnological developments. On the basis of such social approval, the huge potential of this cross-discipline technology can be exploited to the full – which puts wind in the sails of researchers in their everyday work. And this would seem to be necessary, because existing technologies have been hitting the wall for some time. Climate change is an eloquent example, given that traditional methods of energy production – based on burning fossil fuels – have contributed to bringing it about. And new, workable solutions also have to be found for the continuing pollution of the earth by industrial society’s waste products.

Nanotechnology is one of the most promising pacemakers for the future. From 2025, at the latest, the vast majority of all significant new developments will be related to this field of technology. There are not a few people who think the tiny particles with the big impact will point the way out of today’s technological cul-de-sac. Take energy as an example: The Nobel Prize winner Richard Smalley ascribed a key role to nanotechnology in solving the energy issue. High-capacity energy storage or cheap electricity from sunlight – we have come a long way in implementing these technological visions. Nanoparticles will also make it possible to develop new materials that simply disintegrate at the end of their product lifespan without toxic side effects – almost like organic material.

Nanotechnology offers great opportunities, and we are making the risks associated with the particles calculable. This is the only way of ensuring that the future dividends inherent in the nanocosmos will pay off one day.

Maximum security: when it comes to opportunities and risks, research has a particularly important function.
Nano links

www.research-in-germany.de/nano
The central internet portal of the research and innovation location Germany

www.bmbf.de/en/nanotechnologie
Nano website of the Federal Ministry of Education and Research

www.nanonet.de
Link to “Techportal Nanotechnology” platform

www.nano-map.de
Technology Centre database of the Association of German Engineers (VDI)

www.nanoforum.org
Forum for European nano initiatives and activities

www.nano-ev.de
Website of the “Nanotechnology and School” association

http://cordis.europa.eu/nanotechnology
Website of the European Research Commission CORDIS

www.nanotruck.de
Roadshow on the fascinating world of nanotechnology

www.nanoreisen.de
Interactive adventure into the world of the micro- and nanocosmos

www.nks-nano.de
National contact point on nanotechnology, advising on European research funding

www.nanoingermany.com
Presentation of German participants in international nanotechnology trade fairs

http://bildung-beruf.nanonet.de
Educational opportunities in the field of nanotechnology

http://nanobildung.tech-map.de
Topography presentation of educational opportunities in nanotechnology
Words of greeting from Dr Annette Schavan
Federal Ministry of Education and Research

1 Welcome to the research location Germany
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2 Nanotechnology in Germany
AMO GmbH, Aachen | Leibniz Institute for New Materials, Department of CVD Technology, doctoral dissertation, T. Rügamer | © BananaStock Ltd. | © Uwe Bellhäuser – das bilderwerk

3 Research from the very beginning
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4 Nanotechnology in practice
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5 Germany’s next nano generation
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6 Networks and centres of competence
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7 Opportunities and risks of nanotechnology
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