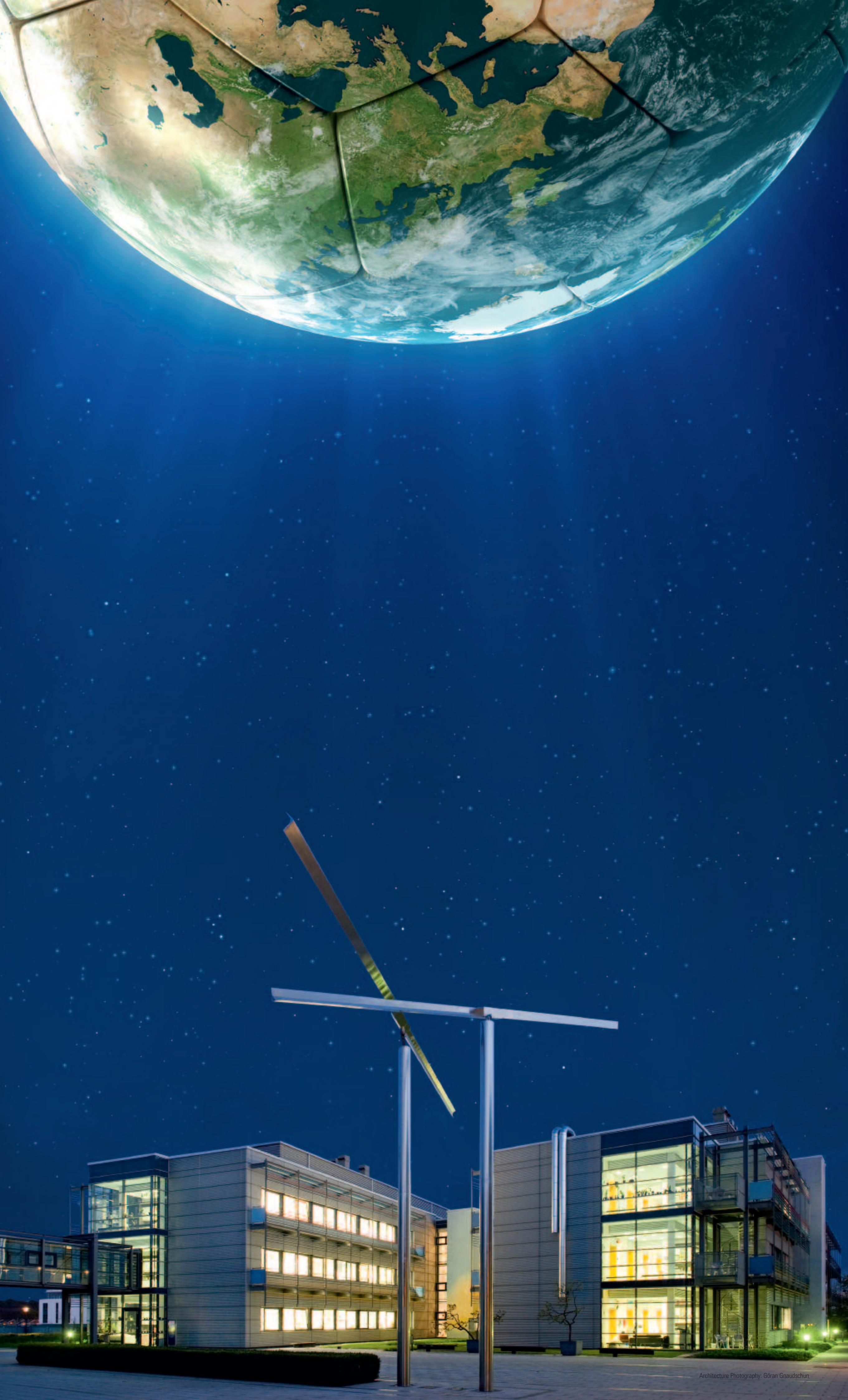
BETWEEN THE WORLDS

THE ESSENTIALS ARE INVISIBLE

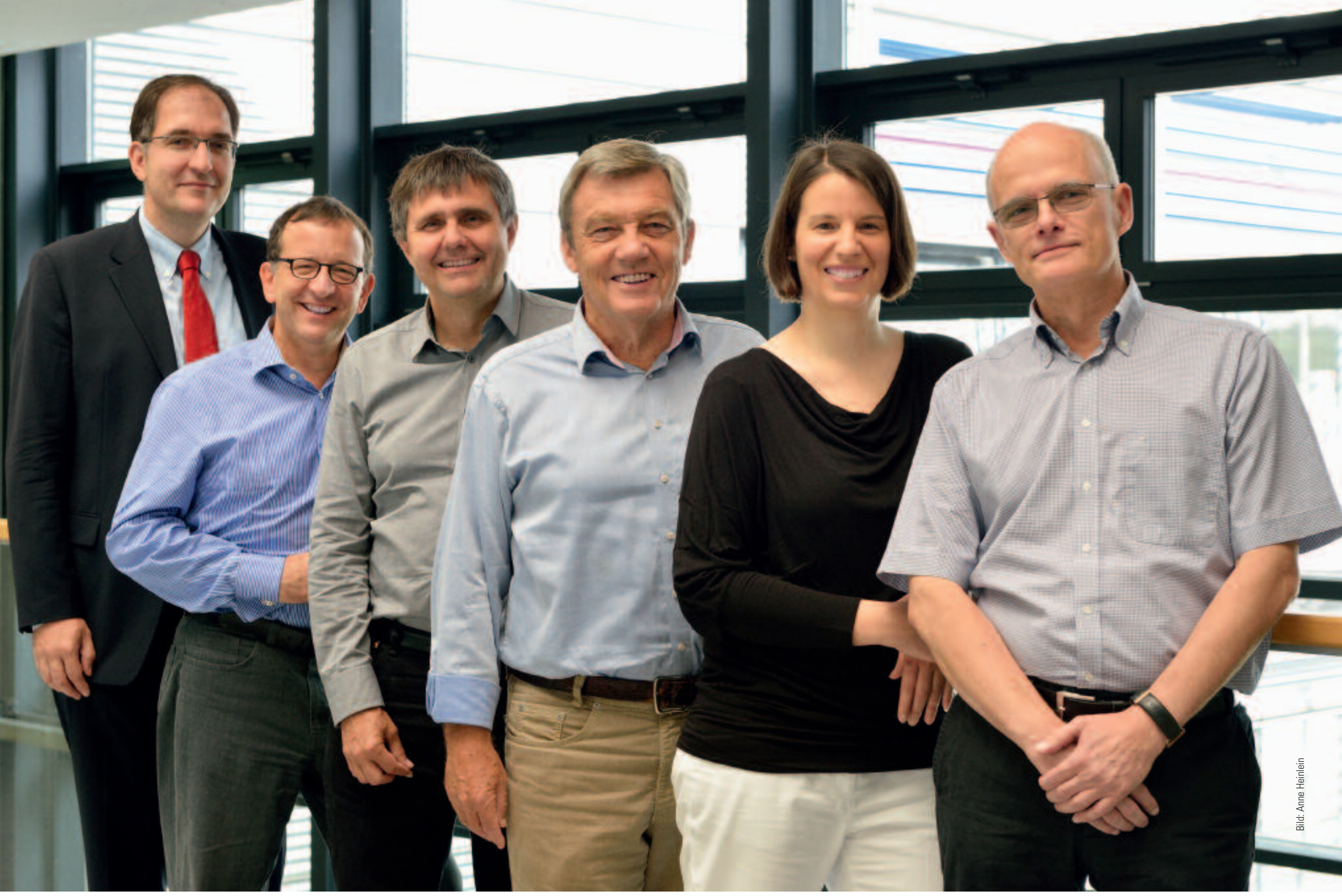
Max Planck Institute of Colloids and Interfaces

MAX-PLANCK-GESELLSCHAFT


Architecture Photography: Göran Gnaudschun

Max Planck Institute of Colloids and Interfaces

Research at the institute aims to understand and control structures of nanometer and micrometer size. A nanometer is a billionth of a meter, a size difference roughly equivalent to that between a football and the earth.



f. l. t. r: Peter H. Seeberger, Markus Antonietti, Peter Fratzl, Helmuth Möhwald (Emeritus), Kerstin Blank (Max Planck Research Group) and Reinhard Lipowsky

The institute

Colloid and interfaces research deals with very small structures in the nanometer and micrometer range. On the one hand, these are a "world of hidden dimensions"; on the other hand, all these tiny structures determine the characteristics of materials and bio-systems on mesoscopic and macroscopic scales. Current research topics include complex sugar molecules, molecular force sensors and engines, mesoscopic hybrid systems, biomimetic membranes and vesicles, as well as the development of sugar-based vaccines and intelligent biomaterials.

Located in Brandenburg´s capital Potsdam, the Max Planck Institute of Colloids and Interfaces (MPICI) was founded in 1992 as one of the first Max Planck Institutes in the new states. Since then, it has evolved into a world-leading research institution with about 350 international employees. The MPI-CI consists of four departments and a Max Planck Research Group. In recent years, the research on biomimetic systems has developed into a joint link between the departments. This manifests itself, inter alia, in the International Max Planck Research School on "Multiscale Bio-Systems", and through the coordination of national and international networks.

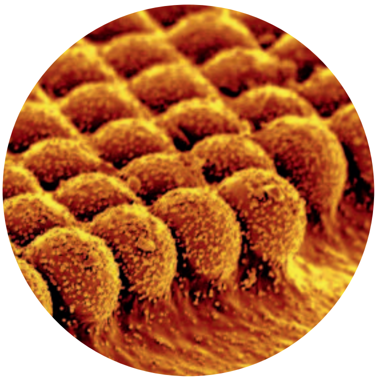
Every year about 25 doctoral theses are completed and two to three researchers are appointed to permanent professorship positions domestically or abroad. Due to its interdisciplinary orientation, the institute cooperates very closely with the four local universities and non-university institutions in the Science Park Potsdam-Golm. Numerous national and international co-operations, as well as dozens of industrial projects, which range from life sciences and materials research, right up to technical applications.


Bild: Norbert Michalke

The research program

Colloids are very small particles. They range in size from nanometer to micrometer. Objects of this size are some of the building blocks that make up organisms. However, they are also essential components of materials, lacquers and emulsions and often determine the mechanical, optical or magnetic properties of these substances. Due to the small size of their components, these materials or structures have a particularly large interface, which in turn influences the macroscopic properties. A deeper understanding of colloids and interfaces is therefore the key for numerous innovations such as the development of "intelligent" drug carriers, innovative biomaterials or new medical treatments.

The interdisciplinary approach links chemical synthesis and biomimetic material development with physical characterization and theoretical modeling. The nano- and microstructures being investigated at the institute are built of special molecules that reach a higher functional order according to the principle of self-organization, without the involvement of external controlling elements.

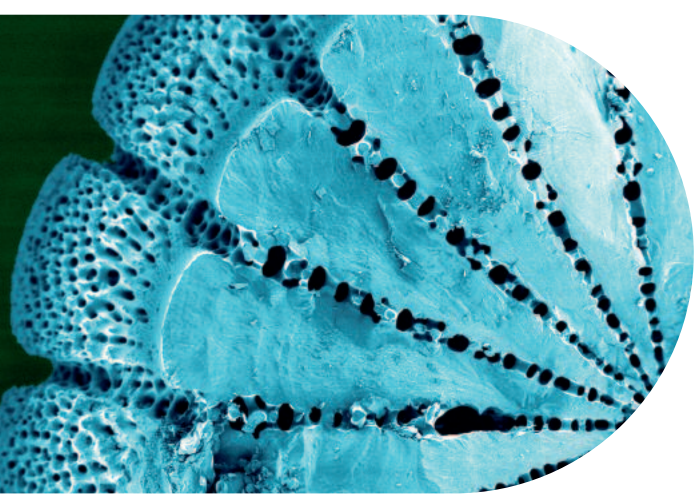


Microparticles made of silicon dioxide, embedded in a soft film and coated with silver on the open side.

BIOMATERIALS

During the course of evolution, nature has developed a variety of materials with outstanding mechanical properties. This includes wood, bones, seashells or even glass sponges from the deep sea. Biological materials are always composite materials made of polymers or sometimes minerals. They are structured hierarchically, which allows the properties to adapt and change over a wide range of structural levels.

Exploration of the internal structures of these materials reveals physical mechanisms that plant stalks use to move and branches use to stretch upwards; how seashells and glass sponges are almost unbreakable; and how the bone can adapt to different requirements. The physical principles of these properties present new ways for optimizing technical materials. In addition, study of the structure and fracture risk of bones, as well as the changes they undergo when diseased are important medical questions that are being examined in co-operation with specialists in the field of medicine.



"Nature has many times fewer materials at hand than humans but achieves quite amazing properties by skillful structuring."

Peter Fratzl, Director of the Biomaterials Department

A look into a sea urchin´s spine: Sea urchins belong to the family of echinoderms. Their body is enveloped by immobile, interlinked skeletal plates consisting of the mineral calcite.

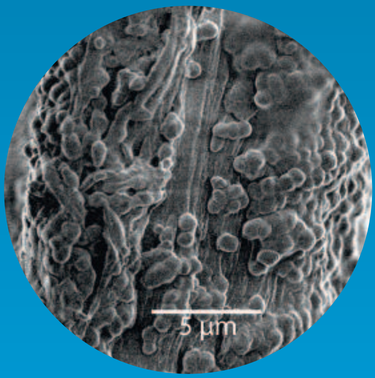
www.mpikg.mpg.de/bm/

Shells hold on surfaces in coastal areas by means of byssus filaments.

Shell fibers for ground adhesion

Shells have adapted to a special mode of life and nutrition in a fascinating way. Despite extreme environmental conditions, they are most commonly found in rocky coastal regions. The development of byssus, a bundle of stable and elastic fibers, plays a key role in explaining this ability to survive in such unlikely conditions. With the help of these fibers, seashells attach themselves to the rocky coastline and thus withstand the constantly breaking waves.

The extremely elastic byssus filaments are covered by a thin yet hard upper skin with a biological polymer reminiscent of sandpaper. Although as hard as epoxide, this knobby upper skin is nevertheless surprisingly durable: it doesn´t rupture or break even when stretched to the maximum. The individual byssus strands are formed in a procedure similar to an injection molding process. The fibers distribute the tremendous energy of the surging waves and protect the shells against abrasion damage from rocks and debris in the water. The protective layer of byssus is apparently able to protect the shell through careful, specific bonds between metals and proteins. It is conceivable that similar strategies could be applied to technically-developed protective polymer coatings.



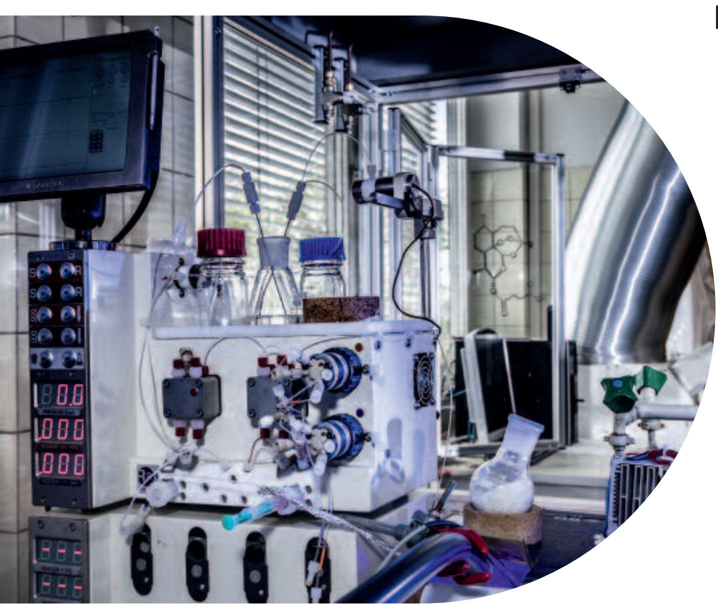
Byssal threads are extensible fibers with a self-healing core and a hard and rough-textured protective cuticle.

BIOMOLECULAR SYSTEMS

For a long time, the numerous naturally-occurring sugars were known only as molecules used by organisms as a source of energy, for example in the form of sucrose (household sugar) or starch, or that plants used in order to store energy. However, some very complex sugar molecules belonging to the carbohydrates substance class are also involved in many biological processes. They coat all cells in the human body and play a crucial role in molecular identification of cell surfaces and thus in infections and immune reactions.

Complex sugars are omnipresent as cell coatings in nature and can therefore also be used for vaccine development, e.g. against malaria. Carbohydrates are thus of significant interest for biology and medicine. The major significance of sugar residues on the surfaces of cells has only been recognized during the past approximately 20 years.

The "Biomolecular Systems" Department founded in 2008 synthesizes "customized" sugar molecules and links them with other molecular groups. These complex carbohydrates can recognize and discriminate between the molecular structures of other carbohydrates as well as proteins and antibodies. One long-term goal is the development of novel sugar-based vaccines.



Apparatus for the continuous synthesis of the malaria drug Artemisinin.

↘ www.mpikg.mpg.de/bs/

Prof. Peter H. Seeberger (left) and Dr. Kerry Gilmore in front of their development – a photoreactor that can continuously produce Artesunate and three other drugs from waste.

Malaria drugs made from waste

Although there is an effective therapy for malaria, this therapy is by no means accessible to all of the 200 million people affected around the globe as it is relatively expensive. A very simple method to synthesize the rather sophisticated design of the Artemisinin molecule has now been found. The active substance formed by Artemisia annua plants is already used within traditional Chinese medicine and has been successfully used to treat malaria.

Chemists use artemisinic acid as a starting material for the synthesis developed here. This by-product has been overlooked to date and is formed during the isolation of Artemisinin from composite plants. This plant waste product is then converted to Artemisinin with very high yields and after just a few minutes using flow chemistry. By coupling continuous chromatography and crystallization, active substances of maximum purity can be produced which meet the requirements of the WHO.

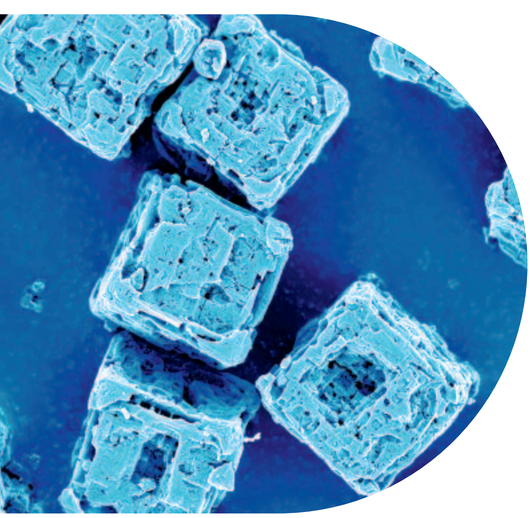
"Since we use all valuable substances of a plant, our process is now significantly cheaper. Not only can we convert the Artemisinin obtained by the extractors directly into drugs; we are now even able to produce additional drugs from the waste."

Peter H. Seeberger, Director of the Biomolecular Systems Department

COLLOID CHEMISTRY

Synthesis of a broad range of macromolecules from which to produce mesoscopic composite systems and hybrid materials is one goal of scientific research. Recently, breakthroughs have been made in the synthesis of functional carbon-based materials based on renewable resources. Research has focused on biomimetic systems that can offer simple and sustainable solutions for global challenges such as the increasing energy demand and a global CO_2 problem.

Chemical systems for artificial photosynthesis, CO_2 avoidance and new energy storage options are representative processes, inspired by nature, that directly convert solar energy into chemical storage and valuable molecules that can be utilized flexibly in both time and space. The goal is to produce quality materials from biowaste that can be used to store energy in batteries or supercapacitors.



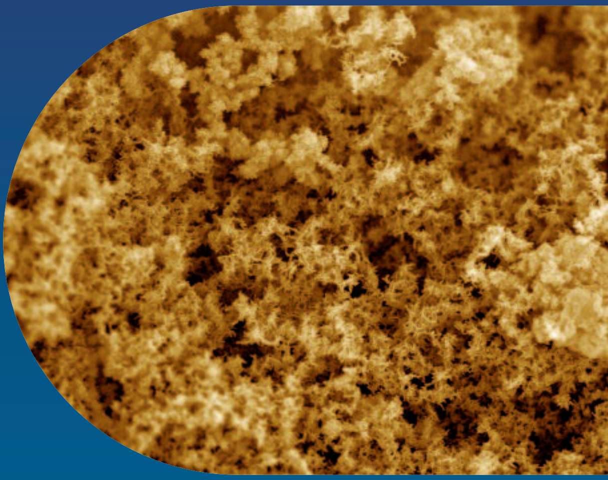
"CO_2 negative technologies and products are needed and developed in our labs. This started with materials from waste biomass, but even sorption materials for binding of CO_2 under realistic conditions are hardly available."

Markus Antonietti, Director of the Colloid Chemistry Department

Carbon structures made of tiny little cubes: this particular form could be produced by targeted self-organizing processes that allow particularly uniform particle shapes and sizes.

www.mpikg.mpg.de/kc/

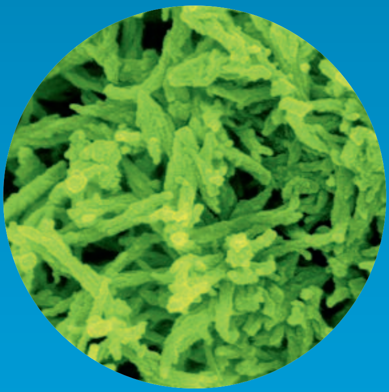
A recipe for nanofibers: specific spherical, layered or fiber-like nanostructures are being produced through carbonization of different organic solvents in a hot molten salt.



Nanostructures: customized coal

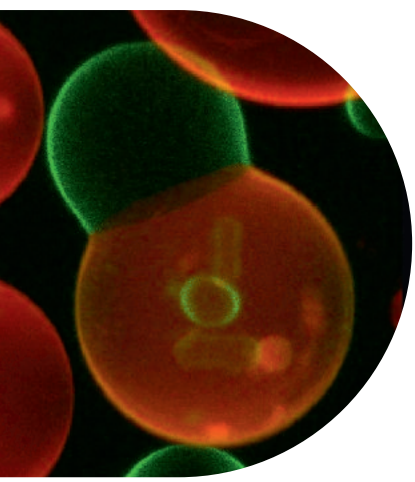
Nanostructured carbons are small and occur as round, layered or fiber-like particles consisting primarily of the chemical element carbon. In addition, they have special catalytic properties. Thus, they are able to reduce the energy consumption for electrolytic cleavage of water. This approach could be of particular interest, for example, when dealing with storage of renewable energies. Due to the large cavities, researchers also envision the use of their nanoparticles for storage of gases such as carbon dioxide. Since such particles are extremely porous and thus have a very large specific surface area, and in some cases are also good conductors of electricity, they are of interest for many applications.

This research is important since the field of energy – as it surrounds us – will undoubtedly change rapidly over the next 20 years. Electromobility will replace combustion engines, decentralized energy grids will be powered by wind and sun. However, these visions cannot be realized until material sciences provide the appropriate key components. In the field of energy storage, for example batteries, expensive and non-sustainable metal systems (e.g. cadmium, nickel, cobalt, lithium) are increasingly being replaced by nanostructured carbons. Made of biomass, they are not only more sustainable and scalable but also less expensive and in some cases even more efficient.



THEORY & BIO-SYSTEMS

Biological and biomimetic systems are made up of molecular building blocks that assemble to form supramolecular structures "on their own". Examples of this include the formation of biomolecular machines with a size of ten to twenty nanometers as well as compartments composed of membranes. Even though the membranes are only a few nanometers thick, they can have a lateral size of many thousands of nanometers. These multiscale systems and processes represent hidden dimensions of self-organization, since observing them directly is possible only to a limited extent.

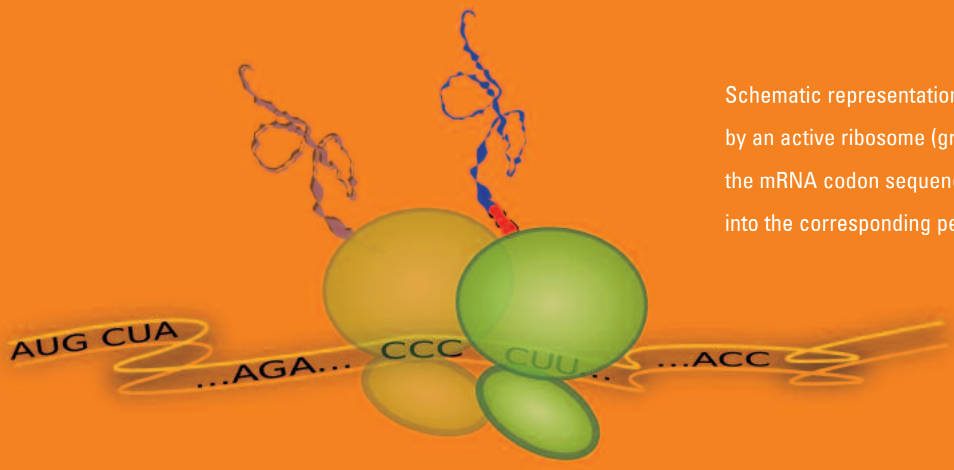


Analytical theory, computer simulation and experimental methods are being used to understand the basic mechanisms and general principles underlying the self-organization of bio-systems at the nanoscale. Of particular interest here is molecular recognition between molecular assemblies, power generation and information processing by molecular engines and motors, as well as self-organization of membranes and vesicles. These systems and processes form important modules for a knowledge-based, bottom-up approach to synthetic biology.

Lipid vesicles with membrane domains

"On the one hand, we want to understand what holds us together at the nanoscale; for example, we want to know how ordered molecular assemblies can result from the interplay of intermolecular and entropic forces. On the other hand, we want to investigate what keeps us going at the nanoscale: how, despite thermal background noise, directed movements can be produced that are vital for cargo transport and information processing."

Reinhard Lipowsky, Director of the Theory & Bio-Systems Department



Schematic representation of protein synthesis by an active ribosome (green) that is translating the mRNA codon sequence (horizontal strand) into the corresponding peptide chain (blue).

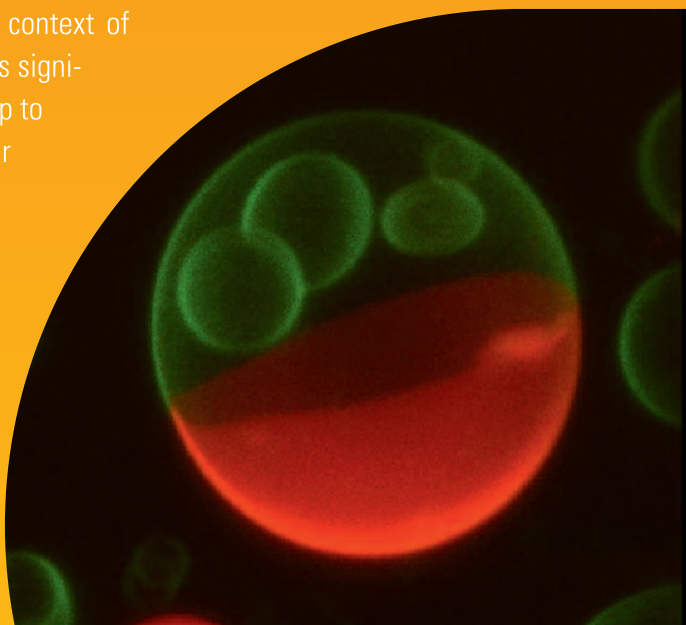
Algorithms of nanomachines

Life is motion – this holds true for the macroscopic as well as for the microscopic world. If we could look deep into a living cell, we would see that new cellular components are constantly produced, modified, transported and ultimately degraded again. These dynamic processes are driven by a multitude of tiny biomolecular machines.

Ribosomes are a particularly impressive example of such "nanorobots" – with a diameter of approximately 23 nanometers, they are responsible for protein biosynthesis in all organisms. In each such synthetic process, a ribosome moves along a messenger RNA that consists of a linear chain of codons.

In doing so, the ribosome translates each codon into a certain amino acid. This translation process consists of a multitude of single conformational changes. Each of these individual steps takes place with a certain speed that can be measured *in vitro* (in a laboratory experiment), but not *in vivo* (in a living cell).

However, using a new theoretical method, it has now become possible to calculate the speeds with which the individual steps take place *in vivo* based on the *in vitro* data. This calculation provides a detailed understanding of the dynamics of protein synthesis. The latter process is important not only for research on antibiotics or codon optimization in biotechnological processes; but also in the context of genetic diseases in which protein synthesis is significantly impaired. The new findings could help to understand these types of diseases and their mechanisms.



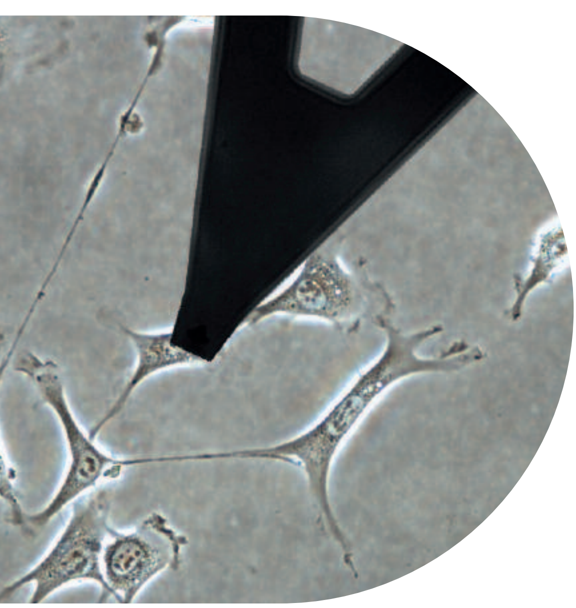
MAX PLANCK RESEARCH GROUP: MECHANO(BIO)CHEMISTRY

For material scientists, biological tissues such as blood vessels and muscles are of major interest, since these tissues have evolved a variety of strategies to respond to external influences. In addition to biochemical signals, tissues and embedded cells detect and also process mechanical forces. Forces play an important role in maintaining healthy tissues. Furthermore, they are also involved in the development of many diseases that are often accompanied by a change in the mechanical tissue characteristics, such as cancer or arteriosclerosis. Despite their enormous importance, little is currently known about how exactly forces are processed in biological tissues.

The Max Planck Research Group Mechano(bio)chemistry investigates how mechanical forces influence biological systems. Scientists in this group are primarily interested in the molecules that recognize and process mechanical information. Usually these molecules are proteins, which due to the acting force change their three-dimensional structure. This in turn results in a change in function.

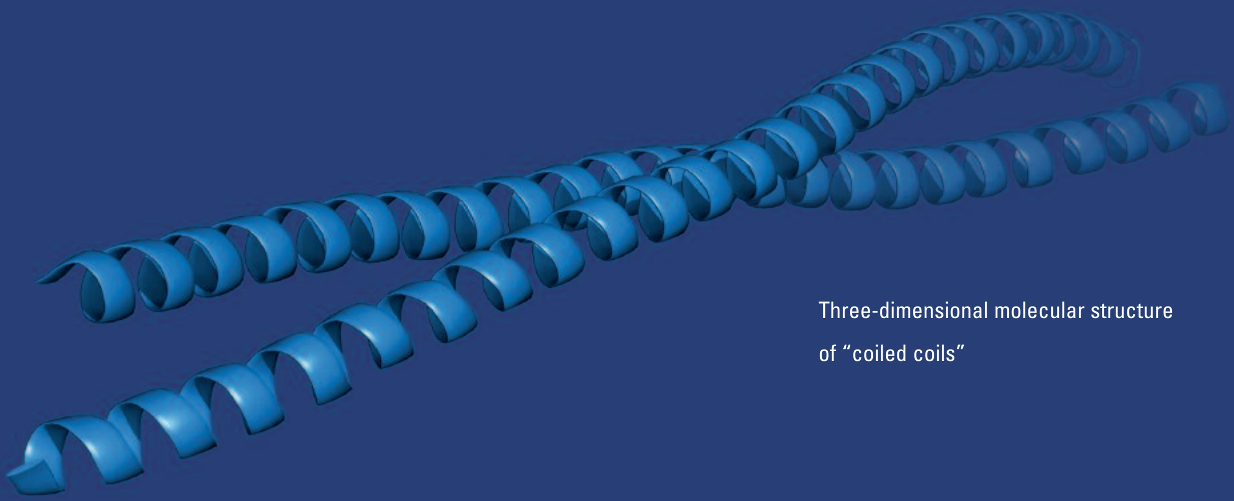
"The goal is not only to understand the molecular mechanisms of these proteins but also to produce specific mechanical protein building blocks in the laboratory. These can then be integrated into biological systems and take over mechanical functions."

Kerstin Blank, Head of the Max Planck Research Group Mechano(bio)chemistry



The cantilever of an atomic force microscope scans cells and determines their mechanical characteristics.

↘ **www.mpikg.mpg.de/mechano-bio-chemistry**

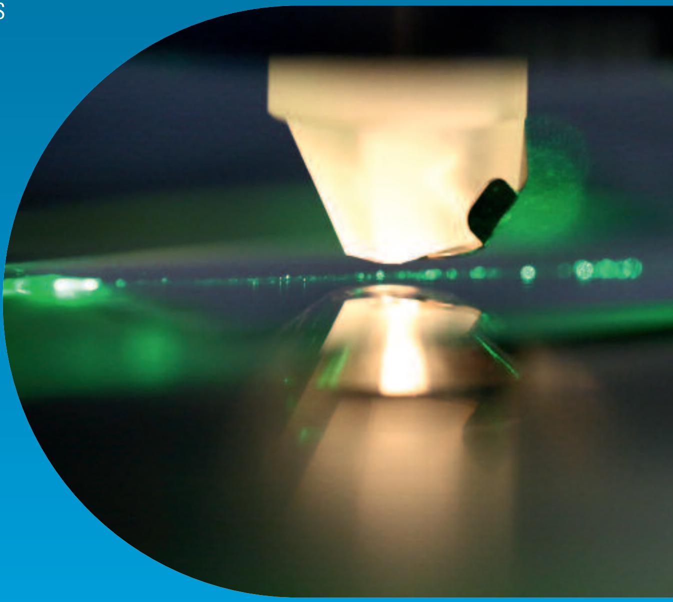


Three-dimensional molecular structure of “coiled coils”

Molecular and cellular power struggles

Every cell in a biological tissue is able to actively generate forces by itself and also measure and process them. At just a few piconewtons, these forces are extremely small. These forces roughly correspond to one ten thousandth of the force originating from the weight of a grain of sand. Such tiny forces can only be investigated using specialized methods and equipment such as the atomic force microscope. The key component of the atomic force microscope is a highly sensitive, miniaturized spring (the cantilever). If forces are at work, the spring will bend and this bending will provide a highly sensitive measure for mechanical processes on both a molecular and cellular level.

Currently, the atomic force microscope is being used to investigate structural proteins and to analyze their stability and elasticity. Helical, (i.e. spiral) structures are of particular interest. These can be found in what is known as “coiled coils” or in collagen. A coiled coil is a helix which itself is wound into a helix with a larger radius. Although many proteins have helical structures, little is known about which factors determine the mechanical properties of the helix. Understanding this relationship not only allows for a better understanding of tissue mechanics, but also for the production of synthetic tissues that mimic the mechanical properties of their natural counterparts.



A combination of atomic force and fluorescence microscopy allows the simultaneous analysis of mechanical and structural characteristics of molecules, cells and tissues.

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL (IMPRS) ON "MULTISCALE BIO-SYSTEMS"

Bild: Göran Gnaudschun

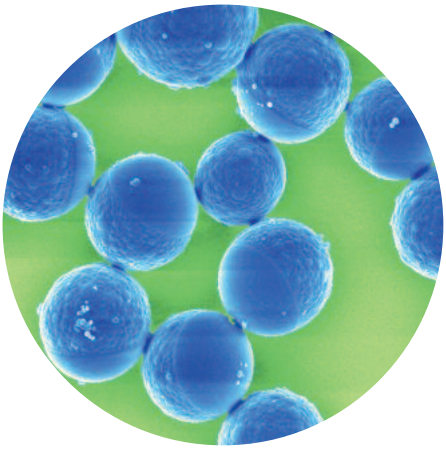
Excellent doctoral training

The International Max Planck Research Schools (IMPRS) have been an essential component of the doctoral program of the Max Planck Society since 2000. Talented young scientists have the opportunity to carry out their doctoral studies under excellent conditions. Common features of these graduate programs at the Max Planck Institutes are the curricula with research seminars and soft skill workshops as well as the close cooperation with universities.

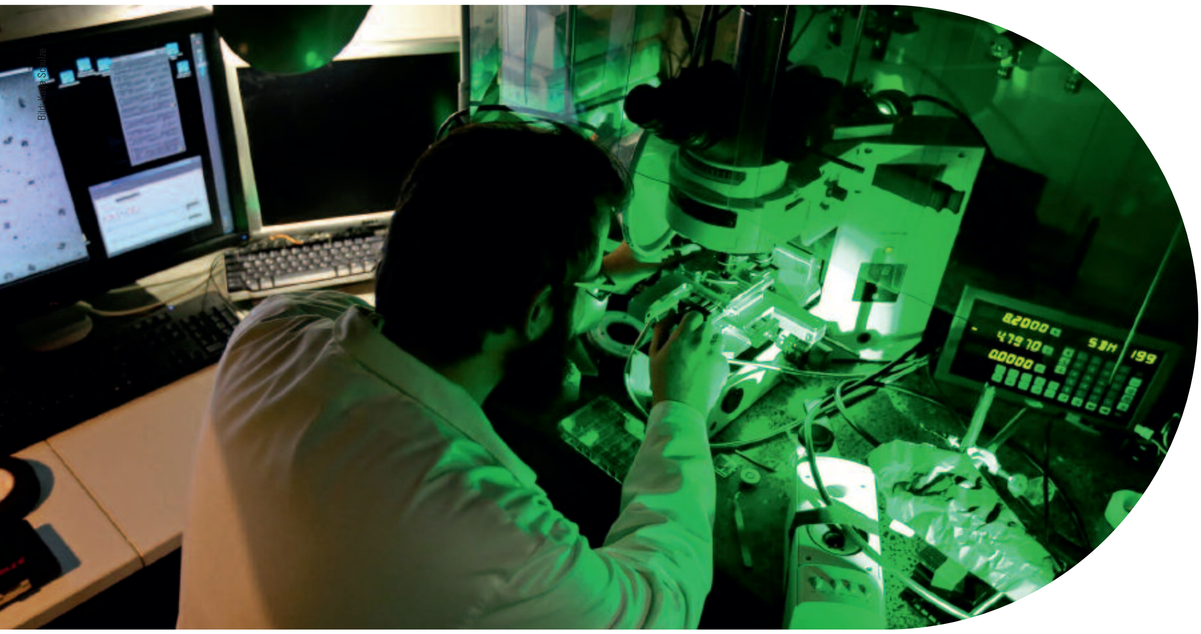
In collaboration with the University of Potsdam, the Free University Berlin and the Humboldt University Berlin the MPICI has established an International Max Planck Research School on “Multiscale Bio-Systems”. The school addresses the fundamental levels of bio-systems as provided by macromolecules in aqueous solutions, molecular recognition between these building blocks, free energy transduction by molecular machines, as well as structure formation and transport in cells and tissues. One main goal of the IMPRS is to gain a quantitative understanding of the processes on the supramolecular and mesoscopic levels in the range of a few nanometers to several micrometers.

Bild: Marco Mauri

The IMPRS is a very international doctoral program. The working language is English and more than half of the doctoral students come from outside Germany. In the year 2017 we had 36 doctoral students from 17 different countries, selected from 1400 applications. The financial support for the IMPRS was approved until mid 2019. In May 2017 an application was submitted to extend the IMPRS until the year 2024.



↘ **www.imprs.mpikg.mpg.de**



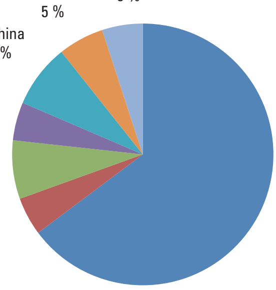
Max Planck Institute of Colloids and Interfaces

Data and figures

Employees

Total number of employees	355
· of which researchers and junior researchers	193
· scholars	16
· of which guest researchers	55
· of which trainees	5

Distribution of nationalities



Spin-offs and patents

The institute currently holds approximately 30 patents. A total of ten spin-offs have been founded between 1993 and 2016: ArtemiFlow, Capsulution Nanoscience AG, Colloid GmbH, FluxPharm, GlycoUniverse, Nanocraft GmbH, Optrel, Riegler & Kirstein, Sinterface und Vaxxilon AG.

Stand November 2017

↘ **www.mpikg.mpg.de**

MAX-PLANCK-GESELLSCHAFT

The Max Planck Society

Over 60 years, the Max Planck Society has been synonymous with excellent, knowledge-oriented basic research in life and natural sciences as well as the humanities. In 1948, the Max Planck Society succeeded the Kaiser Wilhelm Society that had been established in 1911 and in which, in addition to Planck, well-known researchers such as Albert Einstein and Otto Hahn had worked.

Just like the scientists at that time, Max Planck researchers repeatedly enter new dimensions of knowledge right up to the present day – to date, 18 researchers have been awarded the Nobel Prize. Also for this reason, the Max Planck Society, with its 84 research institutes, enjoys a great reputation both in Germany and around the world.

Locations

- Institute / research center
- Sub-institute / external branch
- Other research establishments
- Associated research organizations

The Netherlands
- Nijmegen

Italy
- Rome
- Florence

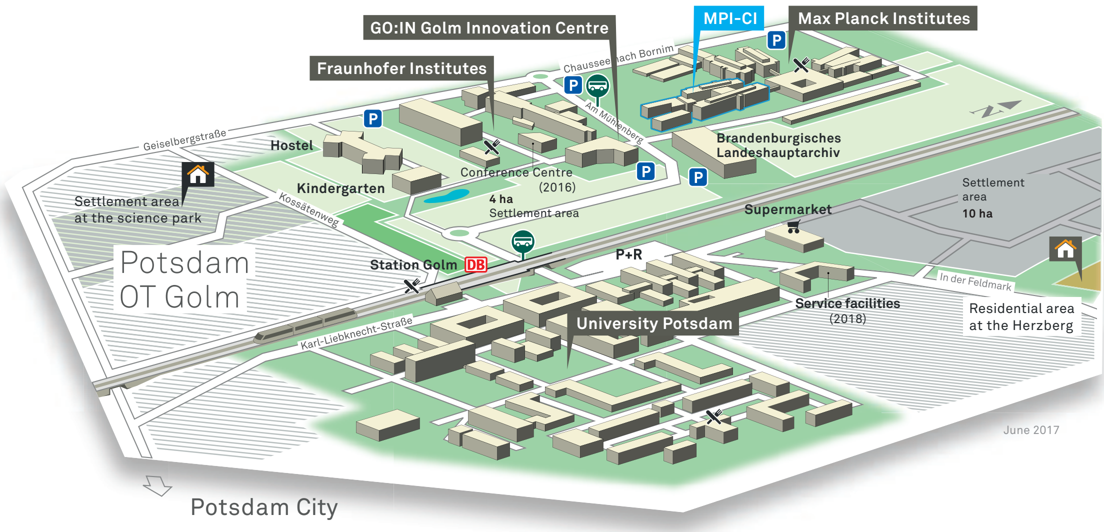
USA
- Jupiter, Florida

Brazil
- Manaus

Luxembourg
- Luxembourg

www.mpg.de

SCIENCE(Φ)PARK
POTSDAM-GOLM



Location

The Potsdam-Golm Science Park is Brandenburg´s largest center for scientific research. Cutting-edge research, training of junior researchers, start-ups and establishing research-related industry form the basis for the performance strengths of the site near the metropolis of Berlin. Its close proximity, with short distances and content-related networking within the science park facilities, offers ideal conditions for creating and using synergies.

This is how you can reach us from Potsdam Central Railway Station:

Bus lines: 605, 606, X5 (to Wissenschaftspark Golm);

Regional train: to Golm Railway Station

Car: e.g. via A10 – Exit Potsdam North or Leest – Direction Golm,

Parking spaces available

↘ **www.wissenschaftspark-potsdam.de**

Glossar

Adenosintriphosphate (ATP): Molecule with three phosphate groups, the splitting of which releases energy.

Amphiphilic: (Greek amphi "both" and philia "love" or "friendship") describes the chemical property of a substance, of possessing water-loving and oil-loving groups. Therefore, they prefer to arrange themselves at the boundary between these liquids.

Biomimetic: (Greek mimesis "mimicking"), mimicking nature. Biomimetic systems are model systems, with which specific biological structures and processes can be mimicked.

Colloids: (Greek kola "adhesive" and eidos "shape, appearance") particles or drops, which are finely distributed in another medium (solid, gas or liquid), the dispersion medium (e.g. blood, clouds).

Emulsions: finely distributed mixture of two different (normally not miscible) liquids, without directly visible separation (e.g. milk, mayonnaise).

Filament: very thin, thread-shaped cell structure (e.g. in muscles), which is created through self-aggregation of protein molecules.

Foams: are comprised of small gas bubbles, which are separated by thin walls or lamellae, which are formed by tensides and water or air.

Interface: Boundary between two phases, e.g. the boundary between two incompatible liquids, such as oil and water.

Lipids: (Greek lipos "fat") are amphiphilic molecules, which assemble in very thin double-layer membranes in water. In living organisms, lipids are mainly used as structural components in cell membranes, for energy storage or as signal molecules.

Micelles: (Latin mica "lumps, small bites"), also called association colloids, are aggregates from amphiphilic molecules/interface active substances, which spontaneously assemble in a dispersion medium (usually water).

Molecular motor: Protein that converts chemical energy into mechanical work. The chemical energy is usually extracted by the splitting of ATP. One of the best investigated motor proteins is kinesin, which transports filaments, vesicles and organelles in all cells of our body.

Nanometer: the millionth part of a millimeter/billionth part of a meter.

Nanosciences: Research dealing with materials in a nanometer scale. The components of this magnitude are large molecules and supramolecular structures, which are structured hierarchically.

Peptide: organic chemical compound which has resulted from linking of several amino acids. These are arranged in a defined sequence into a chain that is usually unbranched. Peptides distinguish themselves from proteins through their size alone.

Planar and non-planar:
Planar – even (plan, "in the surface").

Polymers: (Ancient Greek poly "many", méros, "part") are long chain molecules (linear or branched), which are comprised of the same or different units (the so-called monomers). The adjective, polymer, accordingly means made up of many of the monomeric parts.

Proteins: are polymers, which are made up of amino acids. Proteins are among the basic components of all cells. They not only give the cell structure, but also are molecular "machines", which transport materials, pump ions, catalyze chemical reactions and recognize signal molecules.

Self-aggregation: In water, amphiphilic molecules spontaneously form various supramolecular structures, such as micelles, filaments and double-layer membranes. This process is facilitated by the fine structure of the water, which is comprised of a network of hydrogen bridges.

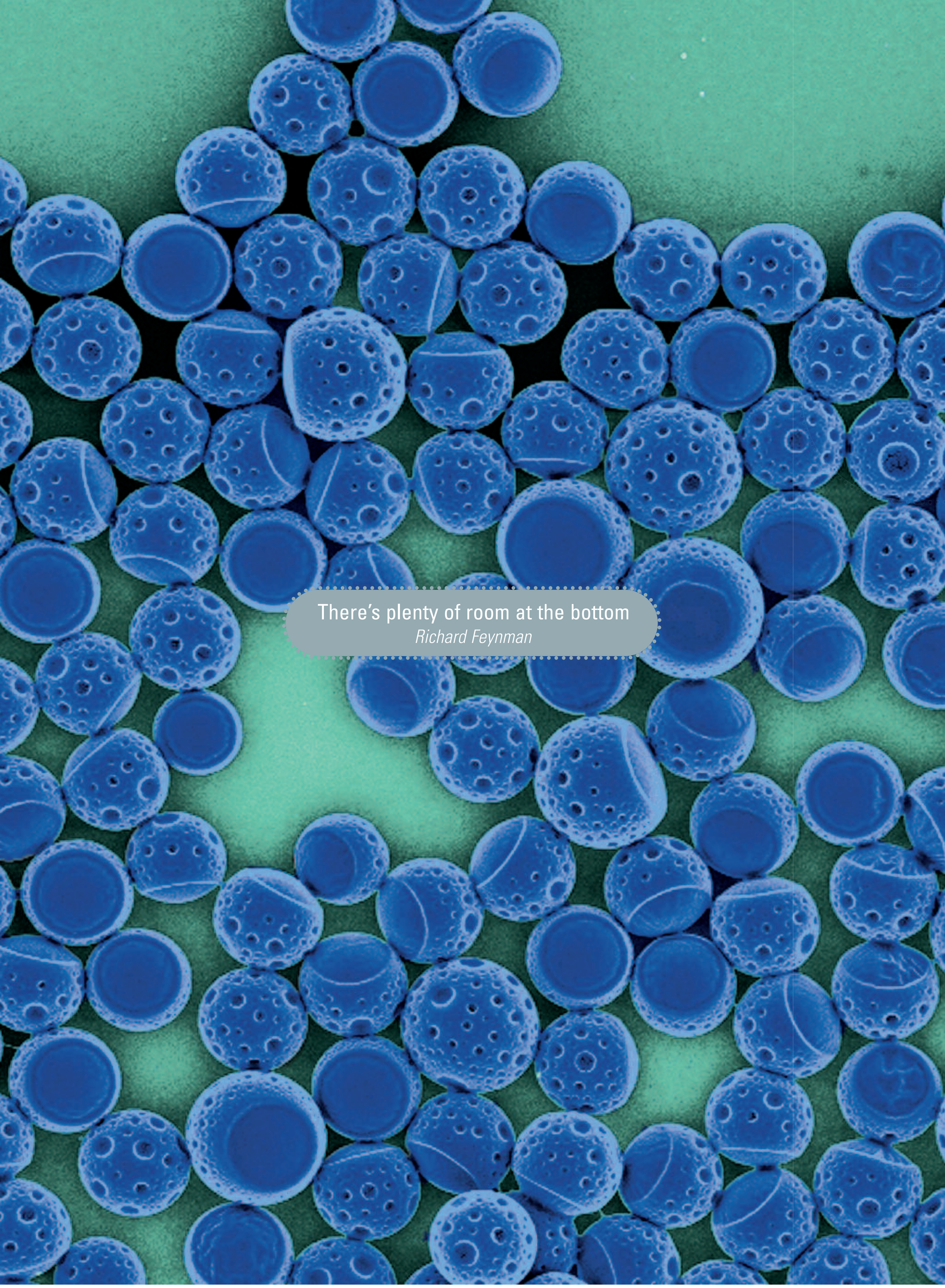
Tensides: are molecules, which have two differently structured ends. One end is hydrophilic, e.g. "water loving". The other end is hydrophobic (water-repellent), or lipophilic ("fat-loving").

Ultracentrifuge: is a centrifuge, which is optimized for high speeds, which can create accelerations of up to 106g. Ultracentrifuges rotate their content very quickly – up to 500,000 times per minute. The rotor moves in vacuum, so that no air friction occurs.

Vesicles: (Latin vesicular "bubbles") are microscopically small bubbles, which are formed from a closed, double-layer membrane and can take on very different shapes. In the laboratory, these vesicles can be produced from a few lipid components. In the cell, such vesicles form small compartments, in which different cellular processes take place.

Impressum
Publisher: Max Planck Institute of Colloids and Interfaces
Address: Science Park Potsdam-Golm, Am Mühlenberg 1, D-14476 Potsdam
Tel.: +49 (0) 331/567-7814 · Fax: +49 (0) 331/567-7875
E-mail: info@mpikg.mpg.de · Internet: www.mpikg.mpg.de
Editor: Katja Schulze
Photography: If not otherwise identified, the rights to the pictures are owned by MPI-CI and pigurdesign.
Design and illustration: pigurdesign, Potsdam
2. Edition, November 2017


Architecture Photography: Göran Gnaudschun



www.mpikg.mpg.de