BETWEEN THE WORLDS

THE ESSENTIALS ARE INVISIBLE

www.mpikg.mpg.de

Max Planck Institute
of Colloids and Interfaces

MAX-PLANCK-GESELLSCHAFT

Max Planck Institute of Colloids and Interfaces

The institute deals with the research and control of nanometre-sized to micrometre-sized structures. A nanometre is a billionth of a metre, a size difference roughly equivalent to that between a football and the earth.

f. l. t. r: Peter Fratzl, Markus Antonietti, Peter H. Seeberger, Helmuth Möhwald and Reinhard Lipowsky

The institute

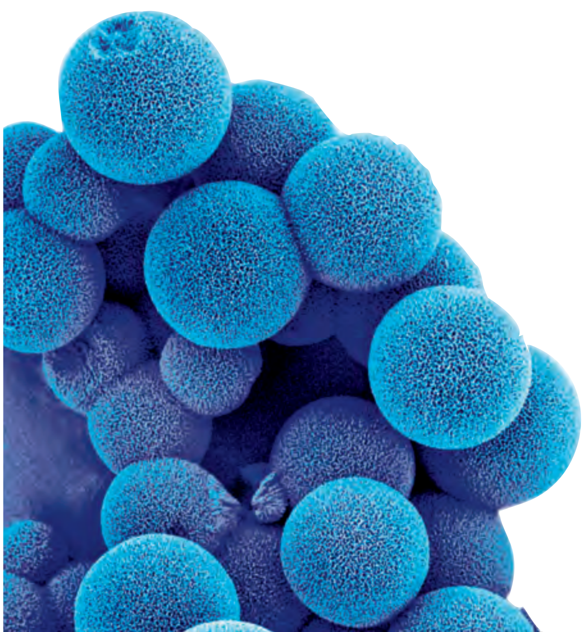
The Max Planck Institute of Colloids and Interfaces was founded in 1992. It is jointly managed by the heads of the departments Biomaterials (Professor Peter Fratzl), Biomolecular Systems (Professor Peter H. Seeberger), Colloid Chemistry (Professor Markus Antonietti), Interfaces (Professor Helmuth Möhwald) and Theory & Bio-Systems (Professor Reinhard Lipowsky). Currently, a total of approx. 350 employees work at the institute, including 160 researchers and junior researchers, as well as 80 guest researchers.

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 "Biomimetic Systems", and through the coordination of national and international networks. Furthermore, the institute is actively involved in academic teaching and training. Every year 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 extra-university institutions in the Science Park Potsdam-Golm and the greater Berlin area. Furthermore, there are numerous national and international co-operations, as well as dozens of industrial projects. These range from life sciences and materials research, right up to technical applications.

The research programme

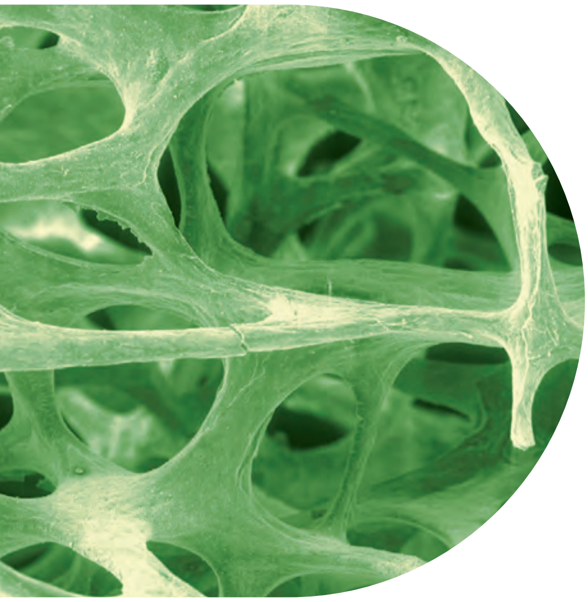
Colloids are particles or drops with a size of less than a thousandth of a millimetre. Even if such small particles cannot be seen without a microscope, they are omnipresent in our everyday world. Colloidal structures exist in nature (blood, milk, clouds), as well as in the synthetic world (inks, adhesives, drugs, liquid crystal displays). Practically all natural tissue in living nature is made up of colloids. These systems of finely distributed materials with dimensions in the nanometre to micrometre range and a high surface/volume ratio are largely influenced by their interfaces. A colloid mass of one gram may have a surface area that can even reach the size of a sport stadium.

The so-called "nanosciences" are interdisciplinary fields of research, encompassing physics, chemistry and biology, and will certainly lead to many innovative technologies in the future, e.g. artificial bones and teeth or implantable sensors. With the help of biomimetic systems, structures and building principles developed by nature during the course of evolution, are transferred to artificial systems and materials. Nature perfectly masters the assembly of functional systems, such as organs or entire creatures, from nanometre-sized components. It has numerous integrated, efficient and elegant solutions available for this. Biomimetic models are a very valuable step for describing the function of biological cells and membranes. The special aspect of the natural system is that it reacts intelligently to environmental stimuli and repairs itself. These are characteristics which are also desirable in many technical systems. On this basis, new, hierarchical materials and systems are investigated, which can be adaptive, self-healing or self-assembling.



Porous amino acid microbeads

BIOMATERIALS

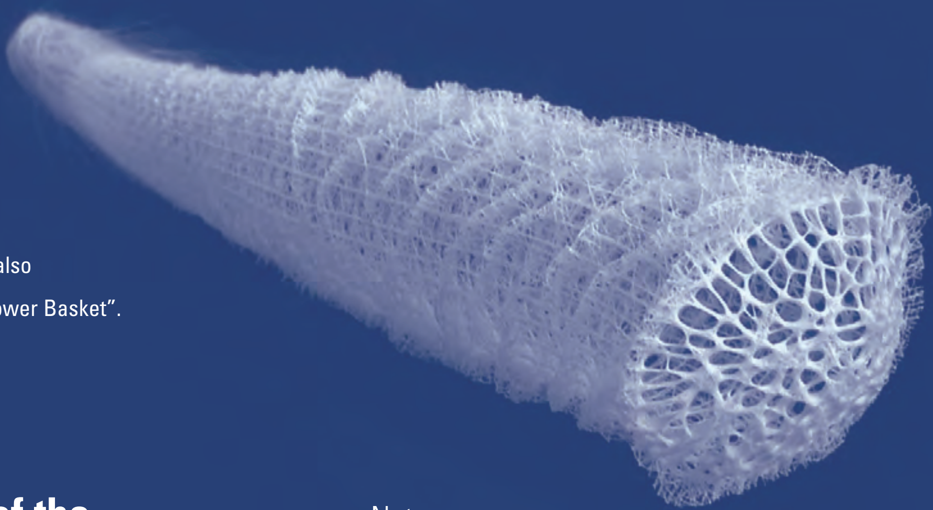


The "Biomaterials" department studies the structural principles governing natural materials, which nature has developed during the course of evolution. The emphasis is on mineralised tissue, such as bones, teeth or mussel shells, on the one hand, and on plants and their cell walls, on the other hand. Interest focusses on the extraordinary mechanical characteristics of these natural materials, which constantly adapt to environmental conditions.

Electron microscope image of the foam-like structure of trabecular bone

The principles of this adaptation process are investigated using physical approaches and computer modelling. In order to determine the hierarchical structure of biological materials, from the molecular level, right up to the entire organ, specific techniques are required. The use of synchrotron radiation plays a central part. The findings gained in this way, about the relationship between material properties and structure, are used for the biomimetic design and development of new materials. In some cases, it is also possible to "copy" natural structures – e.g. the arrangement of pores in wood – directly into technical materials, such as ceramics. The processes for producing such biotemplates are also being investigated. Finally, research is being conducted on the structure and fracture risk of bone, as well as its changes due to disease, e.g. osteoporosis.

www.mpikg.mpg.de/bm/

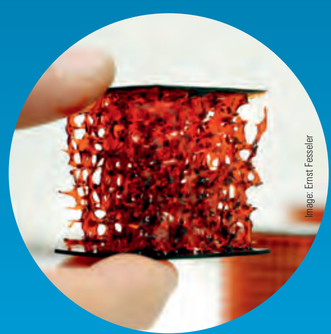


Skeleton of the deep-sea sponge *Euplectella* sp. – also called "Venus' Flower Basket".

Secrets of the Venus' Flower Basket

Nature produces the most unusual building blocks out of the simplest raw materials. The glass sponge *Euplectella* provides a good example of this. It has inhabited the sea for more than 540 million years, lives at a depth of 40 to 5,000 metres and has a cage-like glassy skeleton. Its shape resembles a white cylinder full of fine holes. Shrimp larvae can get inside the structure through these tiny apertures and usually live there in pairs. As the larvae soon become too large for the holes of their abode, the shrimp pair spends their entire life in the sponge, entering into a symbiosis with it. This may explain why *Euplectella* is also called the "prison of marriage" in Japan and is a popular wedding present.

Just how does the sponge manage to withstand the enormous mechanical strain at the bottom of the sea? Aside from the great weight bearing down on it – in some cases the pressure reaches 500 atmospheres – the imprisoned shrimps also maltreat the structure with their pincers. But the prison is escape-proof. Researchers at Bell Labs (USA), the University of California and the Max Planck Institute of Colloids and Interfaces have investigated the structures from the nanometre to the centimetre scale. During the course of their work, they discovered that the cage is constructed from at least seven hierarchically arranged levels – a structural principle of nature, which is of significant interest for engineering high-strength and ultra-light materials. The fact that the sponge manages to combine a whole range of mechanical construction principles on many size scales, from the nanometre to the centimetre range is really amazing. For the researchers, *Euplectella* is a textbook example of how brittle materials like glass can produce non-breakable structures. This provides a completely new stimulus for material research.

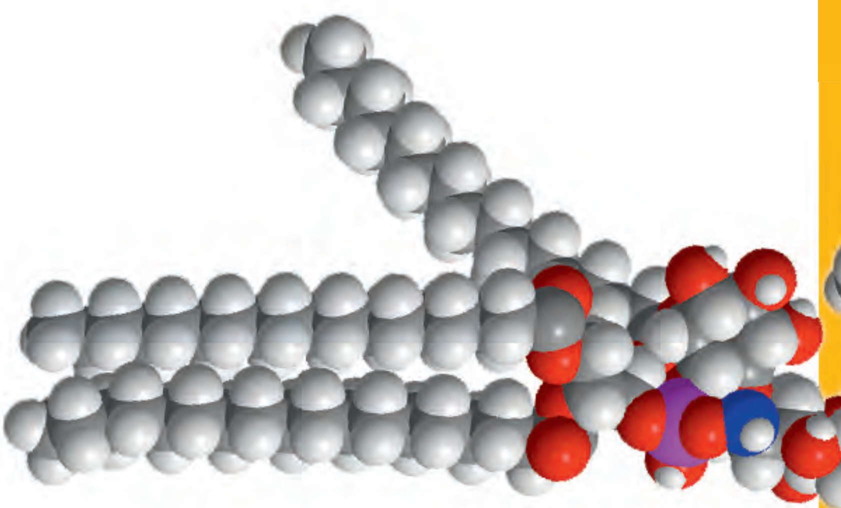


Bone structures from the "wax printer" (rapid prototyping) – replicated from the human vertebral body

BIOMOLECULAR SYSTEMS

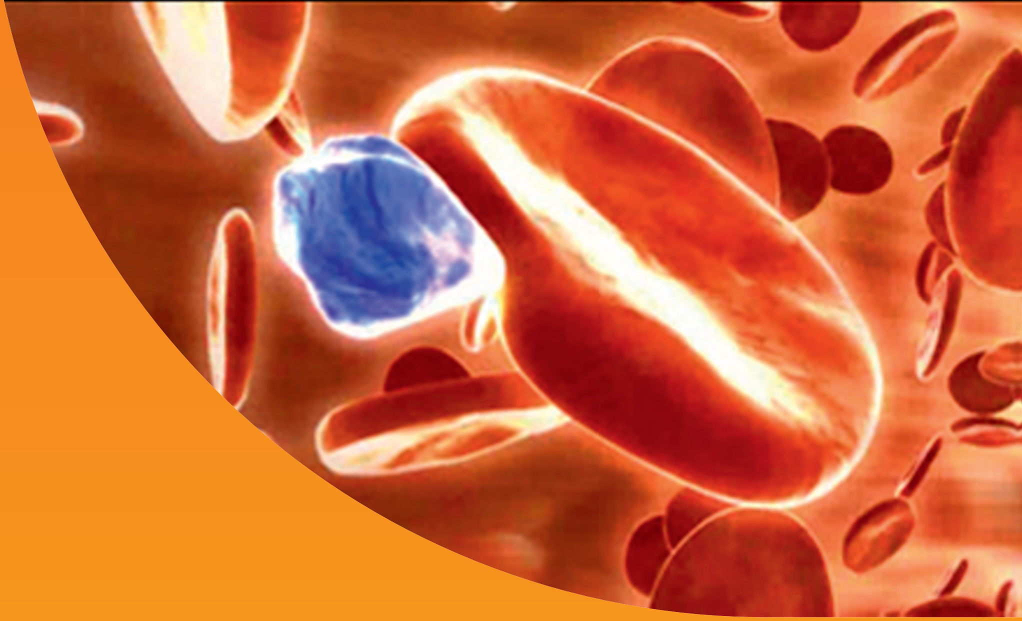
The researchers in the "Biomolecular Systems" department are using new methods for synthesising sugar chains. Until recently most of the known naturally occurring sugars were those that supply energy to organisms such as sucrose (household sugar) and starch (in plants). However, the complex sugar molecules, which belong to the carbohydrate, are also involved in many biological processes. They cover all cells in the human body and play a crucial part in molecular identification of cell surfaces for example in infections, immune reactions and cancer metastases. 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 medicine; the major significance of sugar residues on the surfaces of cells for biology and medicine has only been recognised during the past approximately 20 years.

Until recently, a chemical synthesis method to create biologically relevant carbohydrates with a known structure in large quantities and for biological, pharmaceutical and medical research was lacking. Now, these gaps can be closed with the development of the first automated synthesis apparatus that can link sugar molecules with other sugars or also molecules.



Molecule model of the malaria toxin, GPI

www.mpikg.mpg.de/bs/

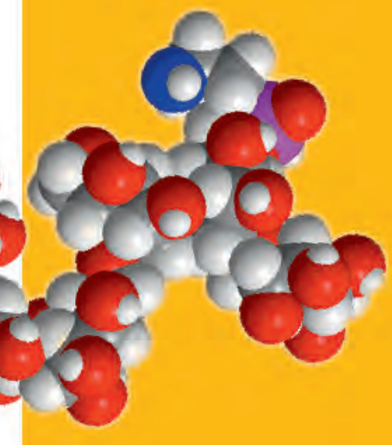


A merozoit (blue) penetrates a red blood cell using a "sugar door opener" and multiplies inside.

From sugar to a vaccine

Antigens are materials, which are recognised by cells of the immune system as being exogenous. Sugar or protein antigens occur on the surface of bacteria, in the sheath of viruses, in pollen that triggers allergies or tumour cells. If the immune system can be stimulated in a targeted manner to form antibodies against such materials, with the help of vaccines, e.g. toxins or cancer cells can be recognised and destroyed. Frequently carbohydrates also including sugars, play a role as biological markers for tumour cells or in bacterial and parasitic infection cycles. When an immune response can be triggered with synthetic sugars, the carbohydrates can serve as candidate agents for preventing or treating infectious diseases, inflammatory reactions and cancer.

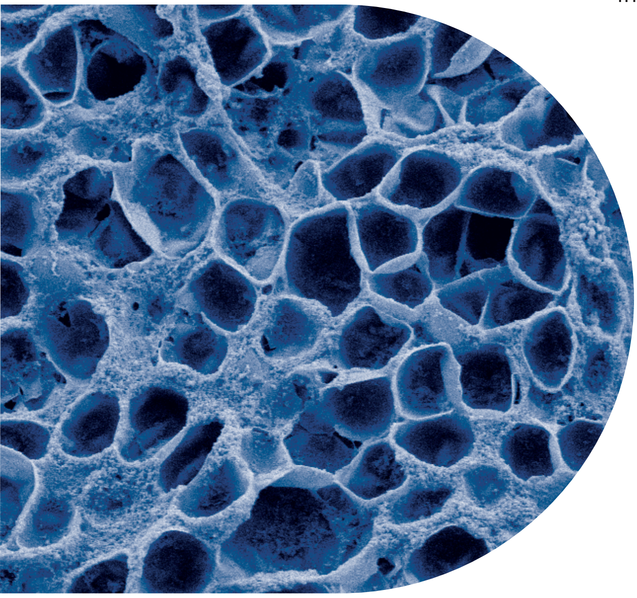
With automated carbohydrate synthesis, the basis for the development of sugar-based drugs and vaccines has been created. The medical possibilities that are opened up by this technology are barely comprehensible: One of the first results was a complete synthesis of the malaria toxin, with which it is intended to develop a vaccine against malaria, a disease which still claims more than two million victims worldwide each year. The effectiveness of such a vaccine has already been proven in animal trials. The development of vaccine candidates against tropical and bacterial vaccines is currently ongoing.



INTERFACES

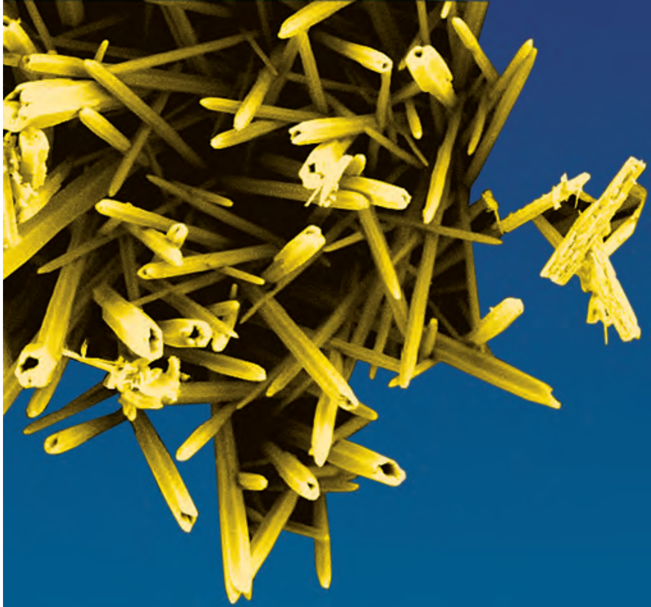
The understanding of molecular interfaces and therefore also their significance for colloidal systems (emulsions, foams, composite materials) is the main subject of the "Interfaces" department's research. Due to the large proportion of interfaces in colloidal systems, understanding these is essential for controlling them. Therefore, numerous state-of-the-art methods have been developed and used in order to characterise the structure and dynamics of molecular interfaces. The findings gained on planar interfaces are also transferred to curved and complex systems, which are relevant for applications (nanoparticles, microcapsules and nanocapsules, self-repairing coatings).

Particular interest is devoted to systems, where the interface characteristics change depending on the environment, which can be manipulated through external influences (intelligent materials) or where the interface carries out a specific function. The latter includes selective transport through membranes and interfaces. More recent research deals with the arrangement and control of the organisation of complex and functional macromolecules and nanoparticles at interfaces. These are, inter alia, important for the purpose of producing self-repairing coatings and controlling the characteristics through external fields (remote control).



Polymer-coated silica microcapsules

www.mpikg.mpg.de/gf/

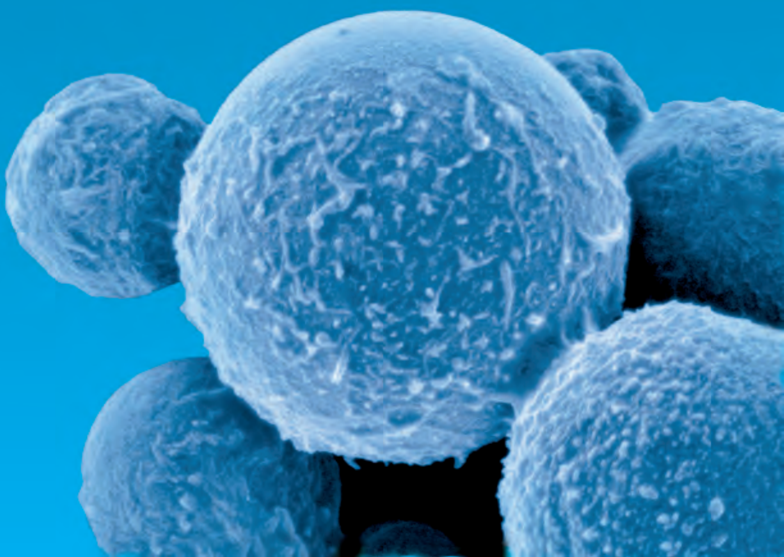


Zinc oxide nanotubes
after ultrasound treatment
of zinc film

Self-healing nanocoatings

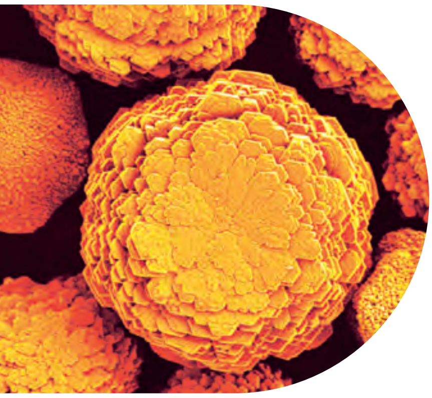
Glass does not rust, but corrosion still gnaws at it. A pane becomes milky and brittle when moisture and oxygen attack it. Most materials – also concrete, stone, but particularly metals – are exposed to destructive processes, which makes the material porous and ultimately unusable. A remedy is promised by invisible, ultra-thin and extremely robust layers on the surface, which protect the material underneath from environmental influences. However, fine holes and cracks in the anti-corrosive layer undermine the protective effect. Water and oxygen penetrate these defects and begin their destructive work. Corrosion spots, which then occur, need to be quickly repaired and, if possible, "by themselves". For this purpose, corrosion inhibitors can be stored in finely distributed nanocontainers and then released very quickly, in order "to block" the holes.

The nanocontainers made of polymers not only ensure that the material, which repairs the damage by itself waits equally distributed in the protective layer for its use. They can also release these substances according to requirements: If the temperature, the electrochemical potential, the local pH-value changes or if corrosion products suddenly occur, the containers open and release their healing content. Depending on demand, they can even store various substances, in order to heal different types of defects under the protective layer.



Polyurethane microcapsules
with silica-nanoparticles
in the shell

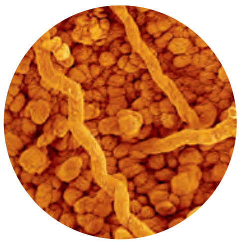
COLLOID CHEMISTRY



Polymer modified calcium carbonate crystal.

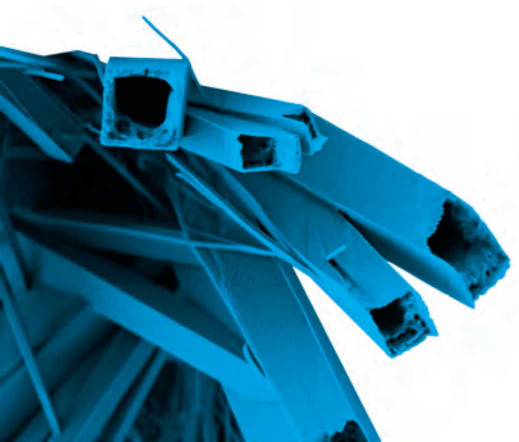
The “Colloid Chemistry” department deals with the synthesis of various colloidal structures in the nanometre range. This includes inorganic and metallic nanoparticles, polymers and peptide structural units, their micelles and organised phases, as well as emulsions and foams. Colloid chemistry is able to create materials with a structural hierarchy through appropriate functionalised colloids. This creates new characteristics through the “teamwork” of the functional groups. With appropriate architecture, these colloids can fulfil very specialised tasks. Single molecular systems cannot do this, due to their lack of complexity. An example for this is skin: There is no synthetic material, which is as soft and simultaneously so tear-resistant and yet is mainly comprised of water. The secret of this also lies in the interaction between three components (collagen, hyaluronic acid, proteoglycan). This unusual combination of characteristics is only made possible by forming a superstructure “in a team”.

The emphasis of the research lies in the targeted coding of structure formation and self-organisation and the linked structural hierarchy. In addition to this synthesis, state-of-the-art analytical methods are also being developed for characterising the structures, e.g. light- and x-ray scattering methods, as well as ultracentrifugation.



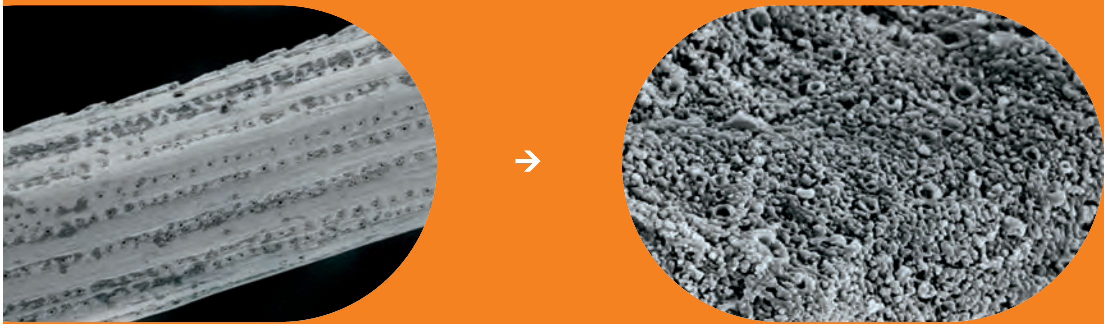
Rod-shaped barium carbonate (witherite) nanocrystals

Hollow square DL-alanin amino acid needles.



www.mpikg.mpg.de/kc/

Biomass: Electron microscope image of pine needles before (left) and after (right) twelve-hour hydrothermal carbonisation at 180 °C



Magic coal from the pressure cooker

Converting straw, wood, damp grass or leaves overnight into coal, this initially brings to mind the philosopher's stone, with which the alchemists of the Middle Ages intended to convert inferior materials into gold. But it really does work: In the Colloid Chemistry department, a process has been developed with which vegetable biomass can be converted virtually entirely into carbon and water, without detours and complicated intermediate steps. The process – called hydrothermal carbonisation – could represent a simplified solution for dealing with the CO_2 problem.

In principle, the charcoal stack functions like a pressure cooker, only at higher temperatures and over longer periods of time. And the recipe for charcoal is surprisingly easy: The pressure container is filled with any plant products, i.e. with leaves, pieces of wood or pine needles. Added to this are water and a pinch of catalyst. This accelerates the splitting of the molecules in carbon and water, so that the process takes place more rapidly than in nature. Then, the pot is closed and everything is heated at 180 degrees Celsius for twelve hours, under pressure and hermetically sealed. After the mixture has cooled off, the pot is opened. It contains a watery, black liquid with finely distributed, spherical coal particles (colloids). All carbon that was bond inside the plant materials is now available in the form of these particles – as small, porous, lignite spheres.

The success is obvious: If you fill biomass, e.g. greenery, into a pressurised container, add a few grains of catalyst and heat all of this, hermetically sealed, to 180 degrees, after twelve hours, you obtain the black powder made up of nanobeads.

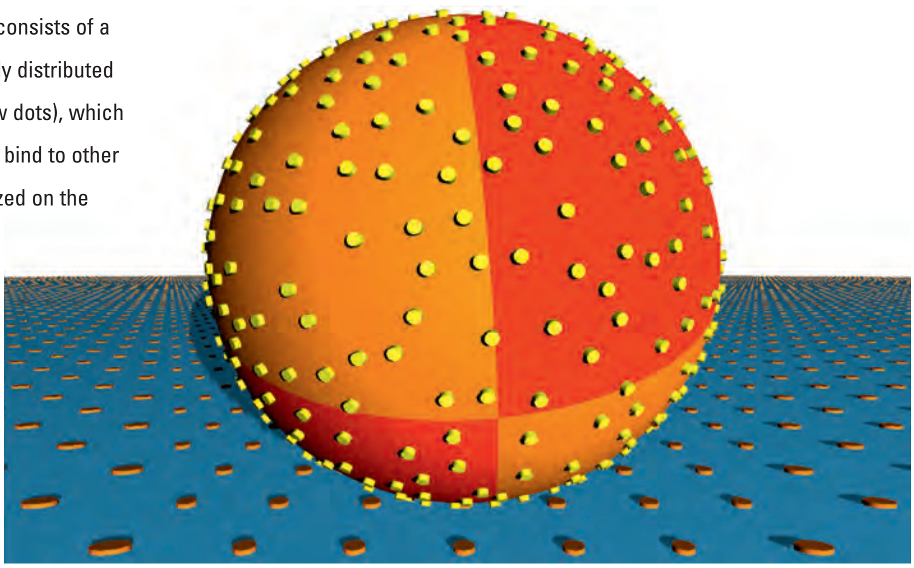
Image: Norbert Michalke

THEORY & BIO-SYSTEMS

In the "Theory & Bio-Systems" department, biomimetic and biological systems are investigated, which are already structured hierarchically in the nanometre and micrometre range. At the most elementary level, these systems involve the behaviour of individual molecular components, such as proteins. On the next level, supra-molecular structures are formed, such as filaments, membranes and interfaces, which are studied using the methods of statistical physics and multi-scale simulation techniques. The integration of diverse classes of molecular building blocks ultimately leads to mesoscopic networks interacting with one another through molecular recognition and exchange processes. Two priority research areas investigated both, theoretically and experimentally, are energy transduction and cargo transport by molecular motors as well as biomimetic membranes and vesicles.

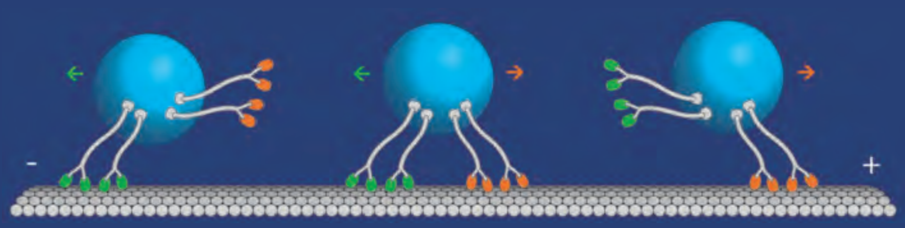
A long-term goal is the identification and elucidation of general laws and mechanisms for structure formation and self-organisation in these systems. One particularly challenging aspect is the entanglement of "passive" assembly based on molecular recognition and intermolecular forces and "active" processes involving energy transduction and force generation by molecular machines.

Computer model for cell adhesion in hydrodynamic flow. The system consists of a spherical cell with randomly distributed adhesion molecules (yellow dots), which are recognised by and can bind to other molecular groups immobilized on the flat substrate.



↘ **www.mpikg.mpg.de/th/**

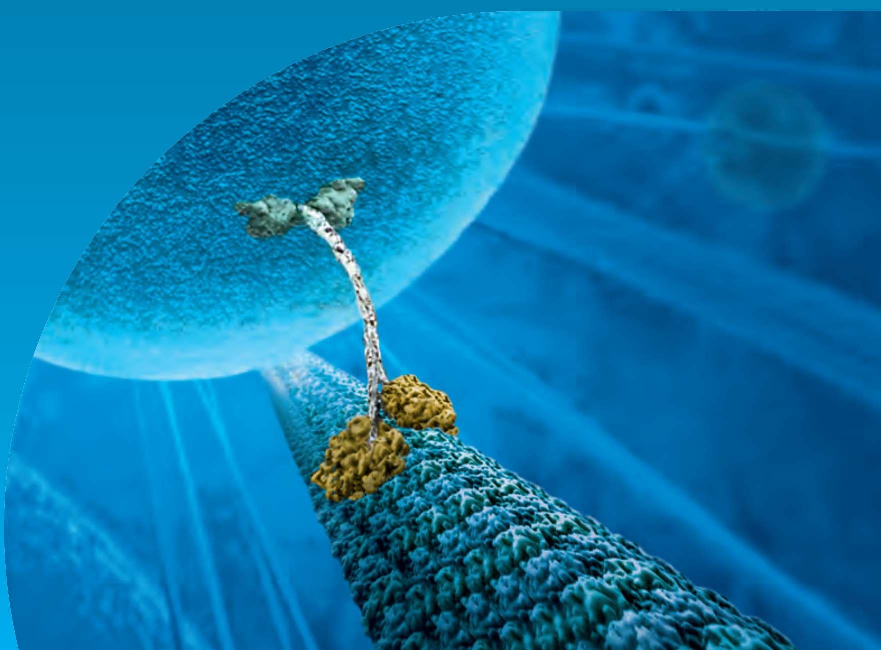
The competition between molecular motors: A blue freight is transported by two motor teams, which run along the yellow filament. The red motor team pulls to the right, toward the plus end (+), the green motor pulls toward the left to the minus end (-). If both teams pull (middle), they mutually hinder each other so that the freight barely moves. In contrast, if a team gains the lead, progress is fast, because the opposing motors are pulled off of the filament.



Tug-of-war in the cell

The transport processes in the cells of our body function similarly to goods traffic on roads or rails. Specific proteins, so-called molecular motors function as “transporters” or “locomotives”: They carry the cellular freight piggyback and move along filaments on the cell skeleton, thereby transporting loads, e.g. vesicles or chromosomes. However, the molecular transporters are a billion times smaller than lorries. Depending on the type of transporter, they can only move to the beginning or end of the filament, need to fight their way through a milling throng, which resembles more an overcrowded pedestrian zone than a motor way – or they are in competition with motors, which intend to run in the other direction. Molecular motors are the “nano-tractors” for all freights, which are transported in the cells of an organism. In addition to their vital importance for the cells’ mode of operation, these molecular motors allow many applications to be anticipated.

In the “Theory & Bio-Systems” department, the transport through molecular motors is investigated theoretically and experimentally. The use of biomimetic model systems, in which the biological complexity of the cells is reduced to a few components, is fundamental to these investigations. This approach allows the systematic investigation of essential sub-processes of the overall cellular activity, on the one hand, and forms the basis for the future development of active molecular components in biomimetic nanotechnology, on the other hand.

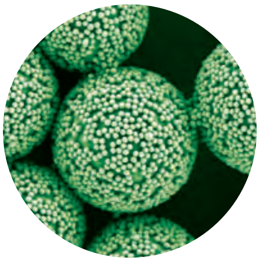


INTERNATIONAL MAX PLANCK RESEARCH SCHOOL (IMPRS) ON BIOMIMETIC SYSTEMS

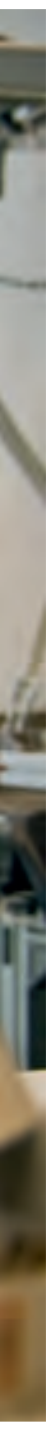
Image: Göran Gnaudschun

The **IMPRS on Biomimetic Systems** is a graduate programme, supported by the Max Planck Society and the State of Brandenburg.

Biomimetic systems are model systems, with which researchers are attempting to understand the complexity of biological systems, as well as developing structures, which sustainably interact with biological systems. The aim of the programme is to increase the research potential of young, motivated doctoral candidates, as far as possible. The IMPRS organises courses, partially also with international guests, which familiarise the students with the theoretical and experimental aspects of biomimetic systems.



The courses are interdisciplinary, the traditional subject boundaries are transcended. Biologists are familiarised with the relevant methods of statistical physics and physicists and chemists are inaugurated in the secrets of molecular cell biology. Furthermore, the doctoral candidates at the IMPRS on Biomimetic Systems mainly deal with their research subject, which they carry out at the Max Planck Institute, at a partner institute or university.



The IMPRS on Biomimetic Systems has an international orientation. The courses are held in English and at least 50% of the doctoral candidates come from abroad. Together with the Max Planck Institute of Colloids and Interfaces, the following universities and institutions are involved in the IMPRS on Biomimetic Systems: University of Potsdam, Humboldt-Universität zu Berlin, Fraunhofer Institute for Applied Polymer Research IAP and the Fraunhofer Institute for Biomedical Engineering IBMT. In total, there are 15 working groups or chairs, in which the IMPRS doctoral candidates carry out their research.

Image: Katja Schulze

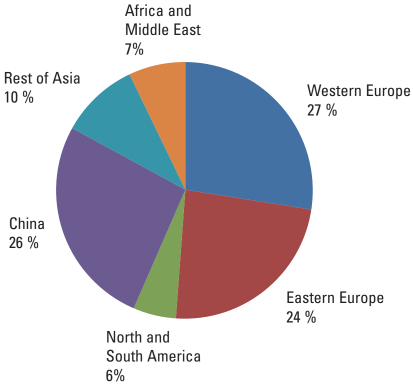
In order to apply for a doctoral candidate position at the IMPRS on Biomimetic Systems, one needs to hold a diploma or a master in physics, chemistry or biology. There is a short registration form on the IMPRS website. After receipt of the form, the coordinator decides whether the quality of the university degree is suitable for becoming an IMPRS doctoral candidate. In positive cases, the full application documents are requested and an invitation is issued to an interview.

Max Planck Institute of Colloids and Interfaces

Data and figures

Employees	
Total number of employees	351
· of which, researchers and junior researchers	159
· of which, guest researchers	77
· of which trainees	8

Distribution of nationalities



Spin-offs	Place	Founded
Riegler & Kirstein GmbH	Potsdam	1993
SINTERFACE Technologies	Berlin-Adlershof	1998
Optrel GbR	Kleinmachnow	1999
Nanocraft GmbH	Engen (Baden-Württemberg)	2000
Capsulution Nanoscience AG	Berlin-Adlershof	2000

As of September 2009

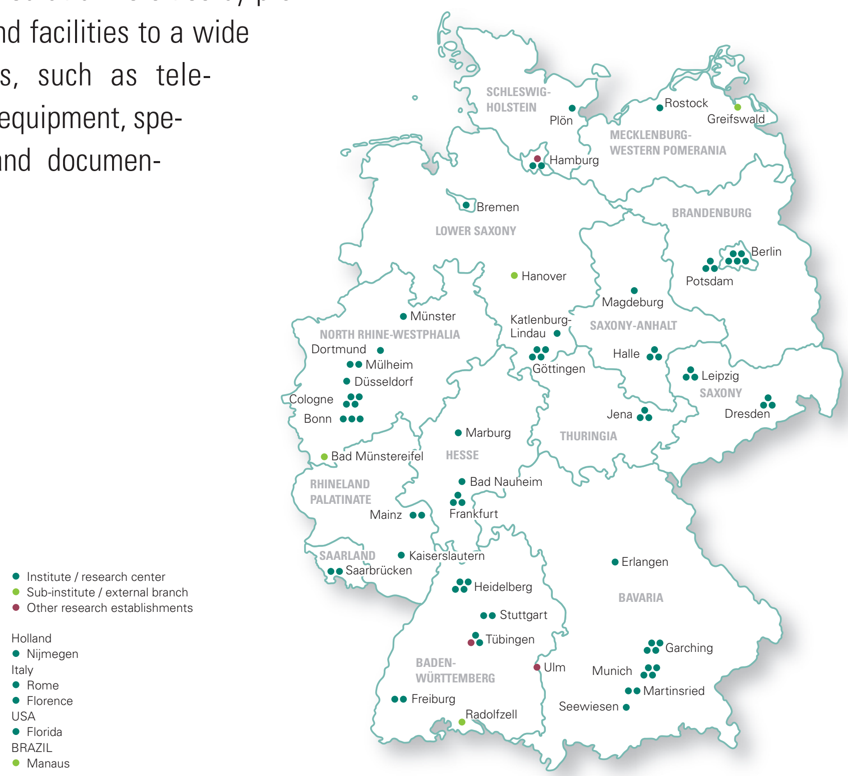
↘ www.mpikg.mpg.de

MAX-PLANCK-GESELLSCHAFT

Max Planck Society

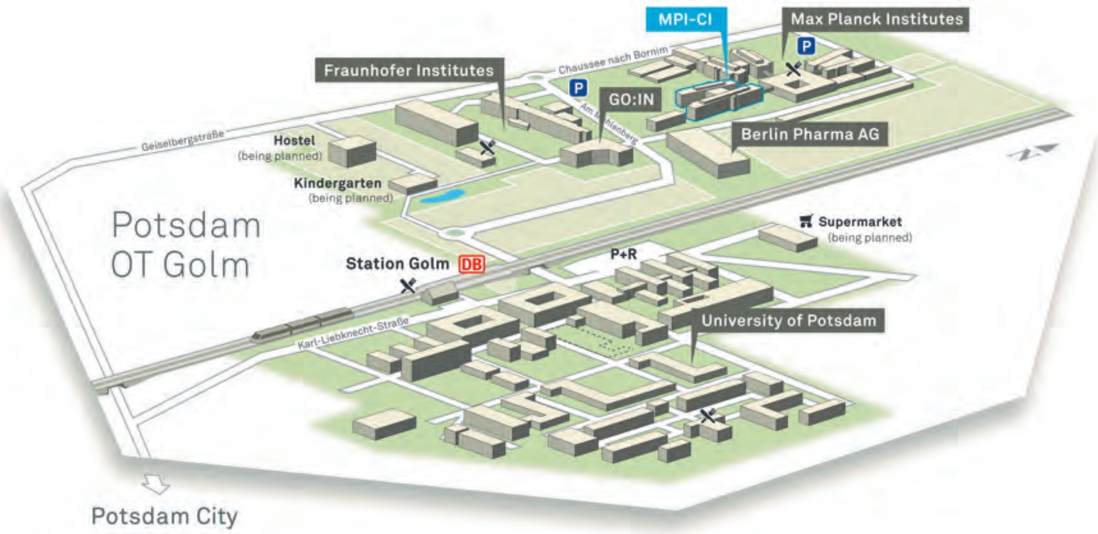
The research institutes of the Max Planck Society perform basic research in the interest of the general public in the natural sciences, life sciences, social sciences, and the humanities. In particular, the Max Planck Society takes up new and innovative research areas that German universities are not in a position to accommodate or deal with adequately. These interdisciplinary research areas often do not fit into the university organization, or they require more funds for personnel and equipment than those available at universities. The variety of topics in the natural sciences and the humanities at Max Planck Institutes complement the work done at universities and other research facilities in important research fields. In certain areas, the institutes occupy key positions, while other institutes complement ongoing research.

Moreover, some institutes perform service functions for research performed at universities by providing equipment and facilities to a wide range of scientists, such as telescopes, large-scale equipment, specialized libraries, and documentary resources.



www.mpg.de

WISSENSCHAFTSPARK
POTSDAM-GOLM



The location

Located just outside Berlin, the Potsdam-Golm Science Park offers leading international research and training for tomorrow's scientists at some of Germany's biggest research institutes and the University of Potsdam, as well as research-based industry for start-ups and small and midsized companies. Proximity and excellent on-site communication and the content-based networking of institutions within the Science Park provide the best possible conditions for the discovery and exploitation of new collaborative ventures.

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

Glossary

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.

Nanometre: the millionth part of a millimetre/billionth part of a metre.

Nanosciences: Research dealing with materials in a nanometre 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 same 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, catalyse chemical reactions and recognise 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 optimised for high speeds, which can create accelerations of up to 10^6g. 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.

Imprint
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
1. Edition, January 2010