:: THE ENIGMA OF THE PLATYPUS

Why are there Different Types of Haemoglobin?

:: Protons in the Turbolayer

:: When Wednesdays are Always Red
How much carbon dioxide do plants bind? And how much do they convert through photosynthesis? This colleague at the Institute of Bio- and Geosciences (IBG-2) is using a spectrometer to measure the amount of sunlight reflected by green plants and the fluorescent light they emit. This allows researchers to calculate the photosynthetic activity and thus to find out how different plants, in particular crop plants, react to extreme environmental conditions and stress. The ground measurements, which are complemented by flight campaigns, are being conducted in preparation for possible use of the measuring method on satellite missions.
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How strongly superglue and magnetic clamps adhere to each other can be determined fairly precisely by mechanical load tests. To date, how strongly a single molecule adheres to a surface could not be directly measured at the microscopic level. Using an atomic force microscope, Jülich physicists have now performed experiments to measure the adhesive force of individual molecules on surfaces. Atomic force microscopes usually detect structures by means of a tiny measuring tip. In order to measure the adhesive force, the researchers sharpened the tip to a single atom. With this tip, they lifted a molecule from a surface step by step, until they had completely removed it from the surface, and determined the force required to do so. Combining these experimental data with computer simulations allowed the scientists to calculate the strength of the bonds and the contribution of different adhesive forces to these bonds, such as van der Waals forces or a chemical bond. This information could help to verify new theoretical models for interactions between molecules and metals.

Rubber rings and other seals are theoretically tighter than was previously assumed. This is the result of simulations using Jülich supercomputers. Seals can stop liquids leaking as soon as just 42% of the leak-preventing surfaces are in contact. Previous theories predicted 50% of the area had to be in contact.

In the current simulations, the researchers determined the contact area more precisely for the first time by taking into account the elasticity of the sealant material. They found that microscopically small peaks of the surface pressed into the soft rubber do not touch all of the seal, but produce additional small gaps. These gaps reduce the contact area, but do not affect the tightness of the seal.

With their work, the scientists from Forschungszentrum Jülich and Saarland University are contributing to a better understanding of the mechanisms involved in leaking seals. Their findings will also allow them to better predict how seals perform as they age.

The new HALO research aircraft (High Altitude and Long Range Research Aircraft) has gone into operation. Jülich researchers were involved in its very first campaign. The TACTS mission (Transport and Composition in the Upper Troposphere/Lowermost Stratosphere) is dispatching six flights from Germany to the Cape Verde Islands. The first of these flights took place at the end of August. During the campaign, researchers are measuring the quantity and distribution of important greenhouse gases such as ozone, carbon dioxide and water vapour in the atmosphere, especially in the boundary area of the upper troposphere and the overlying lower stratosphere (UTLS). The new findings are expected to help optimize chemistry-climate models. On board the research aircraft are three measuring instruments developed by Jülich scientists that detect water vapour and provide information on cloud composition, as well as other data. TACTS is coordinated by scientists from Goethe University Frankfurt.

HALO is a joint initiative of German institutions involved in environmental and climate research and the only research platform of its kind in the world. It can fly up to an altitude of 15.5 kilometres and stay in the air for a maximum of ten hours. This allows it to reach all regions of the earth’s atmosphere – from the poles to the tropics. The aircraft was officially put into operation by German Federal Research Minister Annette Schavan on 20 August.
Detecting Forest Fires, Beetle-Style

Jewel beetles of the genus Melanophila, also known as black fire beetles, are equipped with a special sensor: they are able to detect forest fires from great distances, since their larvae feed on the freshly burnt wood. Researchers at the University of Bonn and their colleagues at Forschungszentrum Jülich have now calculated that these beetles’ biological sensor for thermal radiation could be even more sensitive than infrared sensors currently on the market. The calculations were based on data from a fire at an oil depot in California in 1925, which attracted jewel beetles from a radius of up to 130 kilometres. Using simulations of this incident, the scientists calculated the possible sensitivity of these biological infrared sensors.

These beetles have been on the researchers’ radar for some time. The scientists at Bonn are working on a technical reconstruction of the sensitive infrared sensor. They have already unravelled its functional principle: the beetles have a special sensory organ that contains tiny, liquid-filled spheres able to absorb infrared radiation. As a consequence, the spheres heat up and expand, resulting in a change of pressure that is detected by mechanosensitive sensory cells. The researchers are now working on a technical implementation of this principle, which would significantly improve early warning systems for forest fires.

Improved Diagnostics for Brain Metastases after Treatment

A new method has been developed to facilitate diagnostics after radiotherapy of metastases in the brain: without requiring a tissue sample, it differentiates between changes in the brain that are caused by the treatment and new metastases. Patients are injected with FET, an amino acid that is slightly radioactive. An accumulation of this substance in the brain can be determined by means of positron emission tomography (PET), which will detect a typical accumulation pattern in the case of new metastases, as shown in a patient study conducted by researchers from Jülich, Aachen, and Cologne. According to the scientists, this examination method provides valuable extra information that is required for planning further treatment options without placing a heavy strain on the patient.

Metastases in the brain are a frequent consequence of malignant tumours, such as lung and breast cancer, and are often treated by means of radiotherapy.

A) A new metastasis (white arrow) is indicated by an increased accumulation of FET (red) in the PET image.

B) In case of a radio-necrosis (bottom), the accumulation of FET (green) visible in the PET image is much lower.
Blood Samples in the Neutron Beam

In such diverse creatures as crocodiles, platypuses, humans, and chickens, the haemoglobin in the red blood cells has the same function: it transports oxygen from the lungs into the entire body. An international team headed by Dr. Andreas Stadler from Forschungszentrum Jülich have used their investigative skills to find out details about how and why the haemoglobin nevertheless differs in these species. Their findings are relevant for research on artificial blood, for example.

The peculiarities of the platypus make it a firm favourite in schools and quiz shows: for example, it lays eggs, yet its young are fed by the mother’s milk. Only in Australia does the platypus occur in the wild. It is considered a “primitive mammal” or “living fossil” and is therefore of great interest for evolution research. Jülich physicist Andreas Stadler, however, is interested in the platypus because of another one of its peculiarities: its body temperature of only 33 °C is lower than in almost all other mammals, and no less than 4 °C lower than in healthy humans.

Its low body temperature is ultimately the reason why Stadler and eight other scientists from Germany, France, and Australia have performed sophisticated experiments to study the animal’s haemoglobin – the red blood pigment. In addition, they also investigated the haemoglobin of other blood donors: that of humans, chickens, and saltwater crocodiles. The researchers’ choice also has to do with the respective body temperature of these animals. In chickens, it is particularly high at 41 °C, while in crocodiles, it fluctuates between 25 °C and 34 °C depending on the ambient temperature. For their work, the scientists, who are based at eight different research institutions, used the research reactor FRM II in Garching near Munich and also the most powerful neutron source in the world at the Institut Laue-Langevin (ILL) in Grenoble, France. Their findings were recently published in the *Journal of the Royal Society Interface*.

It was a long journey from Australia to Europe for the blood samples of the platy-
pus and the crocodile, but the research project itself also resembled a long and winding road. It is a prime example of the fact that research takes place in internationally networked teams today and requires state-of-the-art instruments. However, it also illustrates that scientific discoveries are sometimes achieved in a roundabout way.

**TURNING SETBACK INTO SUCCESS**

It all started with a setback in 1994 which, in retrospect, turned out to be a stroke of luck. “It was past midnight when we started the experiment,” recalls Prof. Gerhard M. Artmann, a biophysics professor at Aachen University of Applied Sciences. At the time, he was at the University of San Diego, California, for a research visit, studying the behaviour of human red blood cells drawn into a micropipette, a glass tube strongly tapered at one end – in this case to a diameter of around a thousandth of a millimetre.

When a red blood cell is drawn in with this kind of micropipette, it usually becomes stuck in the tip. If air is subsequently blown into the pipette, the blood cell breaks free again, changing its shape in the process. It turns from a round biconcave disc with a flattened centre into a sphere with little spikes. After a while, the blood cell returns to its original shape.

Andreas Stadler and his international team have found out that the flexibility of haemoglobin in different species depends on their body temperature.

As a biophysicist, Artmann was interested in the mechanisms and substances in the blood cell involved in this transformation. That night he wanted to find out in particular whether the temperature had an impact on how fast the blood cells revert
to their disc shape. This would have been an indication that certain enzymes were involved in the retransformation.

At 36 °C, the experiment went according to plan, but then Artmann repeated it with the same blood cell at a temperature of 37 °C. “The blood cell entered the pipette and – to our great surprise – it took only a few seconds until it had passed the tip,” remembers Artmann. Since his planned experiment was only possible with blood cells that became stuck in the thin tip, he tried again. And again. But, as Artmann recalls, “Only ten out of hundred blood cells behaved they way we wanted them to.” At 39 °C, all cells squeezed through the bottleneck unhindered.

**STRANGE PHENOMENON**

This strange effect, however, had nothing to do with the fact that the experiment was conducted at the witching hour. The results were confirmed in countless later experiments. Artmann says, “Of course, in the beginning we had no idea that this phenomenon would keep us busy for more than 15 years.”

First of all, they attempted to find out which part of the blood cell – the surrounding membrane, the cell structure, or the haemoglobin – was responsible for the effect. The scientists initially assumed that the sudden increase in flexibility was based on structural changes in the blood cells’ shell or structure. In 1998, however, the scientists at Aachen University of Applied Sciences were able to demonstrate in cooperation with a group of scientists headed by Prof. Shu Chien at the University of California in San Diego that, contrary to their assumption, the effect is due to haemoglobin. The oxygentransporting protein abruptly changes its flow behaviour in concentrated solutions between 36 °C and 37 °C.

This finding raised two questions: Does this sudden change in the flow behaviour also occur in the haemoglobin of other species, and if so, does it happen at the same temperature as in humans? The researchers provided initial answers to these questions in journal articles published in 2004 and 2006. In these articles, they explained that they had found the same change in properties in the haemoglobin of the platypus, but at a temperature of 33 °C. The haemoglobin for their experiments came from animals in San Diego Zoo. In 2007, the scientists demonstrated with a comparatively simple method that certain spiral-shaped regions of the haemoglobin lose some of their rigid structure close to the body temperature of the respective animal.

This, of course, raised a whole new issue. How does the haemoglobin of each animal “manage” to adapt this mechanism to the respective body temperature? Structural biologist and biophysicist Prof. Georg Büldt from Forschungszentrum Jülich, who knew Artmann, came up with the idea of using neutron scattering to gain new insights into the different types of haemoglobin. With the help of neutrons, scientists are able to determine the arrangement of atoms in materials. They can also explore the movements of the atoms in these materials (see “The Methods of Neutron Researchers”, p. 10).

Neutrons are electrically neutral building blocks of the atomic nucleus. Free neutrons do not occur naturally. This is why researchers need neutron sources such as FRM II, the reactor at ILL and the spallation source in Oak Ridge, USA.

The Jülich Centre for Neutron Science (JCNS) operates state-of-the-art instruments at all three neutron sources. Even before JCNS was established in 2006, there were already close contacts and collaborations be-
tween Jülich researchers and scientists at these neutron sources. “My PhD thesis, on which I started working in 2006, was jointly funded and supervised by Jülich and ILL,” says Andreas Stadler. It became his task to perform neutron scattering experiments on haemoglobin at ILL, thus implementing Büldt’s idea.

OBSERVING ATOM MOVEMENTS

Stadler used a neutron backscattering spectrometer that measures how the atoms move in the haemoglobins at different temperatures. “The instrument I used, which is referred to as IN13, is able to monitor the tiniest of movements occurring within a hundred trillionth of a second,” explains Stadler. However, the atoms in haemoglobin do not move freely – they are chemically bound to other atoms. Measurements of atom mobility therefore provide information on whether the entirety of chemical bonds in the haemoglobins reacts elastically or rigidly to changes in temperature.

“During a scientific conference in France, where I presented my PhD project, I met Chris Garvey, a scientist from Australia,” says Stadler. Garvey was very interested in Stadler’s research. As soon as the two scientists had agreed to cooperate, Garvey made efforts to obtain blood samples from platypuses – a protected species – and from crocodiles.

The most important result of the measurements: the haemoglobins of different species differ in their degree of flexibility. The haemoglobin of the platypus, which has a low body temperature, is soft and flexible. The haemoglobin of “hot-blooded” chickens is much more rigid. Humans fall somewhere in between these two extremes, not only in terms of their body temperature, but also the flexibility of their red blood cells. “Our measurements confirm that haemoglobin is a highly sensitive molecular thermometer of body temperature,” says Stadler. In an independent research project, Artmann from Aachen University of Applied Sciences also demonstrated another way in which human red blood cells react to temperature: they begin to release cellular water into the blood at temperatures above 37 °C.

The Jülich scientist Stadler, however, is not only concerned with the subject of his research – haemoglobin – but also the research method. “In contrast to our approach, neutron researchers often measure proteins in the form of slightly wetted powders instead of in aqueous solutions,” he says. The most important reason for this is that in the solution, the entire protein moves, not just the atoms inside the protein. This is why it is often difficult to analyse such measurements. In the case of the haemoglobins, howev-
er, the usual method would not have been successful – a fact Stadler has demonstrated in experiments using powder samples at the SPHERES neutron backscattering instrument in Garching, which were supported by Dr. Gerald Schneider from JCNS. “Apparently, wetting the powders is not enough to make them fully biologically active,” concludes Stadler.

**COMPUTER SIMULATIONS**

After the neutron scattering experiments, it was initially still open to speculation which part of the haemoglobin was responsible for adapting to the body temperature during the process of evolution. After all, haemoglobin consists of more than 550 amino acids with a total of around 6000 atoms. The fact that the basic structure of the haemoglobin is the same in different living organisms made it all the more difficult to find an answer to this question.

The SPHERES neutron backscattering instrument in Garching near Munich

**The Methods of Neutron Researchers**

As building blocks of atomic nuclei, neutrons are subject to the laws of quantum mechanics. They can behave both as a wave and as a particle. The waves are about as long as the distances between atoms in crystals. Those waves scattered at the atoms interfere with each other. Similar to the ripples created by throwing a stone into a pool of water, some of these waves amplify each other while others cancel each other out. This results in patterns that provide information on the arrangement of atoms in the crystal. With the help of this principle, neutron researchers are able to analyse structures, including those of powders and giant molecules, as if under a high-resolution microscope.

In other measurements, the behaviour of neutrons resembles that of particles. When they collide with atoms, they absorb and release kinetic energy, like billiard balls. The intensity with which they are accelerated or decelerated depends on the velocity of the atoms, among other factors. This is why researchers can use neutrons to study dynamic processes in materials. Since these processes often take no more than a trillionth of a second, but sometimes hundredths of a second, different instruments are necessary: backscattering spectrometers, time-of-flight spectrometers and spin-echo spectrometers are all specifically designed for defined time and length scales.

Neutrons also have another useful property: they possess a magnetic moment known as the spin. Comparable to a compass needle that measures the earth’s magnetic field, the neutron spin is influenced by the atomic orientation of the elementary magnetic moments in a material. Researchers can therefore also use neutrons to explore the magnetic properties of materials.
Almost identical – and yet adapted to the body temperature ...

For this reason, the researchers contacted Dr. Sophie Sacquin-Mora from Paris Diderot University in France. Garvey knew this specialist for computer simulations from an earlier cooperation. The calculations performed on the basis of data on the structure of haemoglobin and the sequence of amino acids in humans and chickens showed which amino acids directly influence the rigidity of the protein as a whole. The amino acids are located between small holes in the haemoglobin referred to as caves and are known to be important for regulating oxygen uptake. It is obviously not a coincidence that the sequence of amino acids is not the same in this region of the haemoglobin molecule in humans and chickens. Evolutionary processes have optimized oxygen uptake at the specific body temperature of each species and optimized the blood cells’ performance.

These fundamental findings could also have practical implications in the future. For example, scientists worldwide are conducting research on artificial blood that could replace banked blood, for example for accident victims. Those substances that transport oxygen in artificial blood have to be able to traverse the narrowest of blood vessels. It is certainly helpful to know how exactly nature accomplishes this task.

... in direct comparison.

The haemoglobin of chickens and ...
The sample, which is about 3 cm in size, does not look different from any old piece of metal: it is dark grey, hard, smooth, and shiny. Chemically, however, the material is very special, explains Dr. Michael Feuerbacher from the Peter Grünberg Institute: “The structure is highly complex, and the iron and aluminium atoms are situated in clearly defined locations.” Experts call this a complex alloy. Ordinary metal alloys, in contrast, have a very simple structure.

In industry, palladium, a rare and therefore very expensive noble metal, is the material of choice for this purpose today. Together with colleagues from the Max Planck Institute for Chemical Physics of Solids in Dresden and LMU Munich, the Jülich researchers tested the promising iron–aluminium compound to find out whether it could be used as an alternative. Both iron and aluminium abound on earth, which is why they are much cheaper than palladium.

The scientists were excited when the lab experiments showed that the compound performs just as well in the reaction as palladium. “And that this was the result of our very first experiment,” says Feuerbacher. The tried and tested palladium catalyst underwent countless optimization cycles during the last few decades, whereas the aluminium–iron crystal resembles an uncut diamond in comparison. However, a little development work is likely to make this material as effective or even better than palladium. “It’s almost like the alchemist’s dream come true,” says Feuerbacher, “Making gold out of something less valuable.”

IT’S ALL IN THE STRUCTURE

The crystal’s trump card is the internal arrangement of aluminium atoms and iron atoms. The conversion from ethyne to ethene exclusively occurs at the iron atoms. However, this works only if they keep a certain distance from each other. If two iron atoms are located too closely together, the reaction overshoots the target: the ethene formed is converted into ethane, which cannot form polymer chains. If the distance between the iron atoms is too great, however, there is no reaction at all.
The crystals produced by Michael Feuerbacher and Marc Heggen can be used to manufacture tear-resistant plastic carrier bags.

**Chemical All-Rounder**

Ethene is one of the most important raw materials in the chemical industry. The gaseous substance is produced from mineral oil and processed into a number of base chemicals such as ethanol, anthracene, and 2-chloroethanol, which in turn are used to manufacture drugs, colorants, pesticides, adhesives, paints, and much more. About two thirds of the ethene produced is for the manufacture of plastics such as polyvinyl chloride (PVC) and above all polyethylene (PE). The latter is not only used for plastic carrier bags, but also plastic films, freezer bags, buckets, laundry baskets, pipes, and cable insulation. A special variant of polyethylene is even used for high-tech products such as as implants.
How can new antibiotics knock out tuberculosis pathogens? Dr. Lothar Eggeling from Forschungszentrum Jülich has the answer. His team and researchers from the University of Birmingham have isolated an enzyme of the tuberculosis bacteria that can be targeted by new drugs.

Tuberculosis was an epidemic until penicillin appeared on the market in the mid-1940s and banished “consumption” from Europe. Back then, even Alexander Fleming, who discovered this first antibiotic, warned that bacteria could easily become resistant to it. And he was right. According to the World Health Organization, the most important anti-tuberculosis drugs prove ineffective for every twentieth of the more than nine million new patients who contract tuberculosis worldwide every year.

The need for new antibiotics is therefore huge. In developing drugs to combat the bacteria that cause tuberculosis, researchers are focusing on finding their weak points. “We want to know where the bacteria’s metabolic pathways are particularly vulnerable, where their Achilles’ heel is, so to speak,” says Dr. Lothar Eggeling from the Institute of Bio- and Geosciences – Biotechnology. “However, we must understand the structure of the metabolic enzymes before we can target them with potential drugs.”

Eggeling’s team successfully isolated a bacterial enzyme known as DprE1. A new group of antibiotic agents referred to as benzothiazinones bind to this enzyme. The task of DPrE1 is to produce a building block for the bacterial cell wall. “This enzyme is absolutely vital for the bacteria,” emphasizes Eggeling. “That makes DprE1 a particularly suitable target for attacks by antibiotics.”

TWO WEAK POINTS
The British colleagues discovered where these attacks take place. Using crystals made of the bacterial enzyme and different variants of the new antibiotics, they could see where the drugs were effective. The researchers found not one, but two targets: one of the antibiotics docked onto a certain amino acid of DprE1, while another drug variant attached itself to a “loop” structure.

Eggeling says, “The fact that we have identified not just one but two regions in DprE1 as potential targets for drugs significantly increases the chances of producing further variants of this group of new antibiotics and using them to develop new drugs.”
Protons in the Turbolayer

Proton migration along the cell membrane plays a key role in energy production in cells. With the aid of a simulation, Jülich researchers have now been able to demonstrate that there must be a previously unknown boundary layer in which protons move rapidly and efficiently.

Each living cell is a power plant – and what is more, one that produces its own fuel. Understanding how exactly this works is one of the fundamental questions concerning researchers in the life sciences. Scientists know that the molecule adenosine triphosphate (ATP) acts as an energy source for all cells, and they also know that all cells produce ATP using the energy resulting from the proton density gradient between the two sides of the cell membrane. But as far as the details go, a great deal remains to be explained.

One example is the migration of protons along the cell membrane. “The question is this: how are protons able to move in such a way that they reach the proton pumps regulating the gradient quickly?” says Chao Zhang. The Chinese physicist is pursuing a PhD under Prof. Paolo Carloni, head of the subinstitute for Computational Biomedicine (IAS-5), which has been part of Jülich’s Institute for Advanced Simulation since early 2012.

IAS-5’s cooperation partners from Linz, Austria, succeeded in measuring the protons’ high mobility along the cell membrane. “They move as fast as if they were gliding through water, yet they remain attached to the membrane all the while, which should in fact slow them down,” says Carloni.

As the experimental researchers at Linz could not explain this result, Zhang made use of the opportunities offered by computer simulation. “I turned to physics to find the explanation,” says the physicist. Taking quantum mechanical effects into consideration, he carried out an ab initio simulation of proton migration, which means that he recreated the movement using the smallest particles. Simulations require an enormous computational effort, even for a few hundred atoms. With a total of 2000 atoms, the young Chinese scientist’s simulation is one of the biggest ever conducted in biophysics throughout the world.

This level of complexity posed a challenge even to Jülich’s petaflop computer JUGENE. It took the computer 100 days to simulate proton transport for a few trillionths of a second. The results could change the way we understand energy production in cells. “There must be a second layer between the cell membrane and the water. The protons can travel along this layer as fast as if they were in water but still retain a hold on the membrane,” says Zhang. The previously unknown layer is made up of interfacial water, a type of water whose proximity to a surface gives it a special structure. How exactly this layer is formed is a question that will continue to occupy biophysicists in the years ahead.
Mirror, Mirror – and the Wall

Preparations for ITER, the international demonstration reactor for fusion power, which is currently being built in the south of France, are now seriously under way. A reactor wall developed by the Jülich plasma researchers is currently being exposed to final tests. A mirror system, also from Jülich, still has a little more time.

The metal tungsten is really really heavy. That becomes clear when Dr. Philippe Mertens puts a piece into your hand. “Wolfram has emerged as the material of choice for the wall of the fusion chamber,” says the project leader at the Institute of Energy and Climate Research. “It only melts at temperatures above 3400 °C, has a high mass and does not atomize.” It therefore has ideal properties for a material that comes into contact with a plasma at a temperature of 100 million °C.

DRESS REHEARSAL

Tungsten is tried and tested as a material for the filaments in conventional light bulbs and will form a critical part of ITER’s reactor: the divertor. “That’s the ‘plug hole’ of the fusion reactor and the only zone where the wall of the reactor interacts directly with the plasma,” says Mertens, “which is why it has to withstand the greatest loads.”

The many tungsten lamellas, which are only about 5 cm in size but very heavy, are strung together like the links of a bicycle chain. Thousands of these lamellas put together in rows of four form the ring-shaped divertor.

Only a few of them can still be found in Mertens’ laboratory at Jülich. “The lion’s share has already made the journey to the United Kingdom,” he says. At the fusion reactor JET in Culham, the components from Jülich will have to demonstrate in make-or-break tests whether they fully meet the requirements. A total of two tonnes of tungsten have been installed there by Mertens and his team. The less complicated part of JET’s reactor wall consists of the much lighter metal beryllium.

Graphite is still in the running, but is lagging far behind. For a long time, the material consisting of pure carbon — which everyone knows as pencil leads — was considered the most promising candidate for the chamber wall. “However, it has turned out that carbon reacts with the fuel and can form radioactive deposits in the reactor,” explains Mertens.

The official and final decision on a material for ITER’s wall will be taken in no more than one year’s time – based primarily on the results of the tests in the United Kingdom. So far, everything seems to favour the version installed there made of beryllium and tungsten. There is, however, still one uncertainty: “Tungsten must never ever melt during operation,” says Mertens. “We will now have to definitely rule this out in practical tests.”

If the heat is evenly distributed across the entire divertor, it is extremely unlikely that the tungsten will melt. Although the plasma is 100 million °C hot at its core, the temperature drops considerably towards the plasma edge. In addition, the heat is not transferred so quickly to the solid material. It must withstand temperatures of a maximum of 2000 °C – which should not be a problem for tungsten. “But if one of the lamellas protrudes from the wall just a tiny bit more than the others, then it will be in contact with the plasma in that place,” says the researcher. “The temperature would then become too high there, even for tungsten.” However, Mertens is optimistic. “JET is already in operation, and so far, our tungsten wall has been a huge success.”

ALL DONE WITH MIRRORS

Dr. Andrey Litnovsky still has some time before the dress rehearsal. He conducts research on mirrors for ITER. They will direct light out of the fusion chamber so that it can be analysed outside the reactor. Light is created when the...
plasma ignites at high temperatures – which is also why the stars in the sky shine since most of them consist of plasma. “Light says a lot about the properties of a star, and also about those of the plasma: What contaminants does it contain? How hot is it?” says Litnovsky. It would be useless to install cameras and measuring equipment in the wall of ITER’s chamber. The neutrons formed would immediately tarnish the instruments’ optical fibre.

As a mirror, Litnovsky primarily uses discs that are 2 cm in size and consist of the metal molybdenum. His greatest problem so far: “The mirrors quickly become dull because dirt accumulates on their surface. Contaminants are always produced during reactor operation.” This is why the researchers have put a channel in front of the mirrors that lets light fall on them. The channel is covered with a protective flap. “Only the magnetic field produced by the plasma activates the opening mechanism of the protective flap,” says Litnovsky. “While the plasma ignites, however, when the number of contaminant particles in the air is highest, the flap is closed.” In addition, the channel contains mechanical obstacles referred to as apertures that deflect contaminating particles away from the mirrors, making them more difficult for the particles to reach. This is a way of protecting the mirrors.

At the moment, the researcher is testing the system at the US research reactor DIII-D in San Diego. Experiments in the test reactors TEXTOR at Jülich and ASDEX Upgrade in Garching will start shortly. Later, the system will also have to prove itself in JET.
Strong Networks Lead to Extraordinary Gift

Some people’s worlds are a little more colourful than others. They see numbers and letters in colour. Or they taste or even feel words or sounds. This fascinating phenomenon is called synaesthesia.

This condition leads to an unusual linkage of sensory impressions in the brain. In an ongoing study, scientists from Jülich and Munich discovered that certain networks are in many cases more strongly linked in synaesthetes’ brains than they are in the brains of non-synaesthetes.

This gift also has a practical side. Many synaesthetes say that they find it easy to remember telephone numbers or addresses thanks to the extra colour code. “I have a very good memory for numbers,” says Frauke Schröder, who volunteered to participate in the study. “I find it very easy to remember birthdays or dates.”

BRAIN TRAINING

It has been known for some time that certain skills or even physical training leave behind traces in the brain. Learning how to juggle, for instance, changes the outer grey matter in the brain. The brain anatomy of synaesthetes is similar. Two years ago, Prof. Peter H. Weiss-Blankenhorn, a neuroscientist at Forschungszentrum Jülich, discovered that synaesthetes have an increased proportion of grey matter in two regions of the brain. One is the lower right temporal lobe, a brain region specializing in the perception of colour, and the other is the left parietal lobe. “The interesting thing is that synaesthesia doesn’t just lead to a change in the brain region that perceives colour – it also affects the parietal lobe, which is responsible for linking different sensory impressions,” says Weiss-Blankenhorn of the findings.

He sees synaesthetes as a lucky accident of nature. “In contrast to neurologi-
that it is not only the regions responsible for colour perception and sensory linking that have a strong network; the regions of the brain that are responsible for auditory impressions are also involved. Frauke Schröder can also confirm this first hand. When she reads a book, she sees the words as printed in black on white paper. However, if she reads the words out loud or hears them, Friday is coloured green, her own name takes on shades of yellow, and Sunday appears jet-black. “Perhaps it’s because once Sunday is over, the working week begins again,” she jokes. “I always had gymnastics on Wednesdays when I was small. Wednesday has been red for me for as long as I can remember,” says the trainee secondary school teacher.

By reading the brain scans, the scientists were able to tell how strongly rooted the sensory impressions were in each synaesthete. “There is a very clear correlation between the strength of the coupling and the consistency of synaesthetic perception in each individual synaesthete,” says Weiss-Blankenhorn. This is because associations between colours and numbers vary in intensity from person to person. “This is also clearly reflected in the participants’ network structures,” Weiss-Blankenhorn is happy to report.

But the researchers are still unable to answer the question of whether synaesthetes owe their extra abilities to a particular network, or whether it is the abilities themselves that bring about the increased coupling. Anna Dovern says, “In order to find that out, we would have to systematically investigate synaesthetes from early childhood over a period of several years. That would be the only way to establish whether the extraordinary network structures are innate or whether the extra aptitude leaves its traces in the brain over time, similar to the training effect with juggling.”

NO PEACE AND QUIET – EVEN AT REST
The volunteers were instructed to relax, close their eyes and empty their minds. Dr. Anna Dovern, who examined all of the volunteers using functional magnetic resonance imaging, reports: “There is always something going on in the brain, even when you’re at rest. We wanted to find out which regions of the brain are coupled with one another when there are no external stimuli.” The Jülich scientists analysed the complex data sets together with a team from Munich headed by Dr. Valentin Riedl. The results were clear: in synaesthetes, coupling within individual networks was more pronounced, and coupling between networks was moreover three times as intensive. The researchers also discovered that the perception of colour varies from one synaesthete to the next, yet remains consistent throughout their lives.

A particular form of synaesthesia is when sounds produce colour impressions. The American composer Michael Torke, for example, possesses this extra aptitude.

For Frauke Schröder, the days of the week are sorted by colour. Wednesday has always been red for her.

NEW REHABILITATION POSSIBILITIES
Neurologist Weiss-Blankenhorn considers the experiments to be extremely helpful for clinical practice. For the more scientists and doctors know about different healthy networks in the resting brain, the better they can assess functional disorders in the brains of people suffering from serious illnesses. He explains that modern imaging techniques are very effective in finding out which part of the brain has been affected in stroke patients. “But in practice, we frequently see that two patients with a lesion in the same area of the brain ultimately display different deficits,” he adds. “The only explanation is that the network is arranged in a different way in each patient’s brain.” Medical scientists also want to understand how to stimulate patients’ brains so that they can improve the network again. In future, they will be able to compensate for deficits caused by strokes, either partially or under the right conditions – even fully.
Focus on Watson’s Successor

The European Research Council has faith in Prof. Paul Kögerler. The Jülich chemist has been awarded € 1.5 million – Europe’s most generous grant for early-career scientists. His research aims to pave the way for the next generation of computers.

Watson is the name of the IBM supercomputer that outwitted two winners on the US quiz show *Jeopardy!* in 2011. It proved that artificial intelligence is capable of beating human intelligence, even when it comes to complex linguistic and knowledge-based tasks. However, what the public did not see were the 80 quintillion processes per second that Watson needed to do so and its excessive power consumption.

This is where Prof. Paul Kögerler from Jülich’s Peter Grünberg Institute – Electronic Properties (PGI-6) comes into play. “Microelectronics must break away from conventional computer designs and let itself be inspired by the non-binary workings of the brain. Only then will it become dramatically more energy-efficient and be in a position to process even more complex tasks than Watson’s artificial intelligence,” says Kögerler describing the envisaged revolution.

While the Watson experiment proves that artificial intelligence can logically combine facts from a huge database, the human brain is much more economical: it consumes only about as much energy as a 50-watt incandescent bulb. When it comes to associative processes such as understanding language, our brain is still head and shoulders above any computer. Kögerler’s research therefore aims at more powerful and energy-efficient transistor technology. He believes magnetic molecules that can be activated with minimal voltages will be the basis of this technology. The European Research Council (ERC) has now confirmed that his research approach is extremely promising by awarding him an ERC Starting Grant.

With the funds from the European Union, the race for transistors of the next generation is ready to go into the next round. Throughout the world, scientists are tinkering with the basic idea that Kögerler and his team are also working on, namely replacing the silicon in transistors with magnetic molecules. “What is interesting about these molecules are their nonlinear effects,” says Kögerler. “Nonlinear means that these molecules exhibit sharp, or clearly measurable, changes in their behaviour even if the voltage applied only changes a tiny bit.”

As a consequence, a transistor based on a magnetic molecule could be controlled precisely with a minimal voltage – and thus extremely low energy requirements.

**CONTACTING AS THE CRUX**

The hitch: nobody has yet managed to reliably use the switching properties that result from the magnetic states of individual molecules and can be very complex. This is because any external influence – including contact with an electrode – changes both the magnetic
properties and the electronic properties of the molecules. In addition, it sometimes matters where exactly the contact takes place on a three-dimensional molecule structure. The reactions of the magnetic molecule may be different depending on the place of contacting, and is entirely incalculable unless it can be located precisely. Overcoming this technical hurdle is what Kögerler aims to do. He wants to find out how to exactly place the contacting of the magnetic molecule. In this way, the reactions of the central molecule to changes in the voltage should be reproducible. The advantage of Kögerler and his team is that the metal-oxide nanomolecules they use are proving to be more stable than conventional magnetic molecules tested elsewhere.

“We use materials known as polyoxometalates – stable molecular molybdenum and tungsten oxides. We are able to adjust their structures and electronic states very precisely,” says Kögerler. The objective of the researchers is to chemically attach precisely positioned functional groups to these molecules. Ideally, these “adhesive molecules”, as Kögerler refers to them, determine neither the electronic properties nor the magnetic properties of the central molecule. “We are preparing the ‘handshake’, so to speak, between the magnetic molecules and the electrodes,” is how Kögerler describes his approach. If all goes according to the team’s plans, the connecting elements will then easily make contact with conducting as well as non-conducting components.

Paul Kögerler and his colleagues are focusing on four molecular groups, but he is not yet prepared to reveal their names. At the moment, transistors of the future are fiercely fought over. “For the time being, we are investigating all four candidates in parallel in different working groups,” says Kögerler, explaining their strategy. “This gives us at least two years to bring together our two strands of research: the functionality of the magnetic molecules on the one hand and their possible integration into a transistor layout on the other hand.”

“This kind of major project can only be implemented in an excellent research environment such as ours at Aachen and Jülich,” says Kögerler, who is head of a group for molecular magnetism at PGI-6 and a professor of inorganic chemistry at RWTH Aachen University. “The nano spintronics cluster tool* at PGI-6 in particular allows us to produce and examine our molecules and their functional groups with unprecedented precision by means of various analysis and preparation methods.”

As part of JARA-FIT**, the 41-year-old has been examining molecular magnetic matter since 2006. By the end of the year, his team is expected to grow to 20 members. If the combined research efforts can reliably contact the molecules by 2017, their application in transistors could then be tested. And being ready for practical tests is a prerequisite for Kögerler’s application for follow-up funding: the ERC Proof of Concept Grant.

** ERC Starting Grant**

The ERC Starting Grant for excellent early-career scientists in Europe provides funding to the tune of up to € 1.5 million over a period of five years. It aims to support pioneering and visionary basic research that transcends the boundaries to applied research, those between the classical disciplines, and those between research and technology. RWTH Aachen University acts as the administrative host institution for Kögerler’s ERC Starting Grant.

* Jülich’s nano spintronics cluster tool combines several functions in one machine: ultrathin layers and shapes can be produced from individual atomic layers, combined and analysed in individual steps without removing the samples from the protecting high vacuum. In addition, the device can also apply an electric voltage to the samples.

** Jülich Aachen Research Alliance, Fundamentals of Future Information Technology section
Scientists from Forschungszentrum Jülich and RWTH Aachen University certainly enjoy being able to work with rare jewels from time to time and not just mundane everyday tasks. They are particularly interested in the crystals presented on these pages due to their inner beauty. Some of them exhibit extraordinary electronic effects, such as memristive behaviour, multiferroic or exotic magnetic orders. If researchers could find out how to control these phenomena more effectively, this could mean ground-breaking progress for the next generations of computers and facilities for storing or converting renewable energy, such as batteries and fuel cells.

Some of the materials studied have been used commercially for many years. Lithium niobate (LiNbO₃), for example, is often used in mobile communications technology. Others are candidates for novel, non-volatile data storage, or for highly sensitive sensors, such as the multiferroic material LiFeSi₂O₆. It simultaneously displays magnetism and electricity, the latter being partially coupled to the former.

Researchers in the FIT section of the Jülich Aachen Research Alliance study the mechanisms behind these special electronic properties using ultrahigh-resolution electron microscopy and other methods. Memristive cells based on SrTiO₃ change their electrical resistance depending on the amount of electric current that has already flowed through them. These cells are regarded as a possible alternative to conventional transistors – they are faster, smaller, and much more energy-efficient. Moreover, they are able to process intermediate states in addition to “one” and “zero”. They are thus perfectly suited for building components which are able to learn, similar to biological synapses.
**Lithium-iron pyroxene (LiFeSi₂O₆)**

**Applications:** potential for data storage and sensors  
**Special property:** magnetoelectric behaviour  
**Production:** flux growth technique – solution crystallization at high temperatures

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**Lithium niobate (LiNbO₃)**

**Applications:** non-linear optical components, lasers, filters and modulators, holographic data storage  
**Special property:** refractive index depends on electrical fields and incident light  
**Production:** Czochralski process – pulled out of a melt

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**Langasite (La₃Ga₅SiO₁₄)**

**Applications:** sensors, temperature-resistant filters and resonators, laser material  
**Special property:** piezoelectric – mechanical pressure is coupled to electric voltage  
**Production:** Czochralski process – pulled out of a melt

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**Neodymium gallate (NdGaO₃)**

**Applications:** substrate for high-temperature superconductors and compound semiconductors in optoelectronics  
**Special property:** appropriate lattice structure for growth of layers  
**Production:** Czochralski process – pulled out of a melt

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