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Success – “If that doesn’t top it all!” The exclamation uttered by Barbara Ertl, wife of our latest Nobel Prize winner Gerhard Ertl, just about sums it up. A Nobel Prize is still the greatest, craziest, finest and most incredible thing that can happen to a scientist. The fact that two Nobel Prizes will go to Germany this year is also a huge success for the country itself. Both are richly deserved: Peter Grünberg, who works as a physicist at the Research Centre Jülich, discovered what is called the GMR effect, which makes the huge storage capacities of modern computer hard disks possible. Gerhard Ertl, Director emeritus at the Fritz Haber Institute of the Max Planck Society, developed the methodological foundations for an entirely new area of chemistry. Thanks to his research, we now understand in detail how chemical reactions take place on surfaces, and therefore also how catalysts work. The applications of his findings range from artificial fertilizers to semiconductor technology.

Both successes demonstrate the high standards of basic research in Germany. And the applications of these discoveries show how urgently we need such research. Basic research opens the doors to entirely new fields, paving the way for both science and industry and creating a basis for genuine innovations. Urgent global problems, such as climate protection, feeding the world’s population or tackling spreading epidemics can likewise be solved only with the aid of fundamental new knowledge. Successful basic research calls for staying power.

The Max Planck Society is in the fine position to safeguard long-term research programs, thanks not least to our subject-related independence and our stable financing. We pass on both to our Directors. The successful results prove this strategy to be correct: since the Society’s founding after World War II, 17 Max Planck scientists have received Nobel Prizes, the most recent being Theodor Hänsch, who won the 2005 prize for physics.

Resolve – In his book GUT FEELINGS: THE INTELLIGENCE OF THE UNCONSCIOUS, Gerd Gigerenzer, Director at the Max Planck Institute for Human Development, relates a wonderful anecdote: A professor – an economist, to be precise – is unable to decide whether to heed the call of another university. In response to the advice that he should follow his own theory of the maximization of benefits, he replies in exasperation, “Enough of that – this is serious!” The story strikes me as very close to life. For one thing, I find Gigerenzer’s remarks on intuitive decisions very illuminating. And for another, enticing talent away from the competition is almost as common in science as it is in football. The Max Planck Society is a successful player in this contest. We regularly succeed in attracting top scientists from renowned research institutions worldwide. Already this year we have recruited researchers, both female and male, from Oxford, Yale and Princeton. Their gut feelings surely played a part in...
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New Materials

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Macho Tendencies in Females

In most animal species, the males compete for access to the females. In a few species, however, including the African black coucal, the sex roles are reversed. Scientists at the Max Planck Institute for Ornithology have now shown that the sex hormone testosterone, which occasionally makes males into machos, is most likely involved in aggressive and territorial behavior of female black coucals. (Developmental Neurobiology 67, 1560–1573, 2007)

To attract a partner, males must find a territory and defend it against rivals – a typical pattern found in many animals. Females, on the other hand, are choosy and often select a partner according to the quality of his territory. In contrast to males, females typically have much higher confidence in the fact that they are the actual genetic parent of their young. Therefore, it is primarily the females that take care of the offspring, supported to a greater or lesser extent by their male partners. Most female vertebrates actually raise their young all by themselves. However, in less than one percent of all bird species, the roles are reversed and the females aggressively defend their territories and compete for males while the males provide all the care for the young.

The African black coucal is one of these rarities. During the rainy season, females develop a magnificent breeding plumage and establish large territories. And their behavior becomes more macho in other ways as well: they constantly sing to advertise their possession of a territory, and aggressively drive away other females. At the same time, they welcome males – the more the better. Each female mates with up to three males.

Each of the male partners of a female territory owner builds his own nest. The female lays up to seven eggs in each nest, but this also marks the end of the care that a female gives to her brood. “Only the father incubates the eggs and then feeds the helpless nestlings until they leave the nest after two weeks. He then continues to feed the fledged young for a few weeks thereafter,” remarks Wolfgang Goymann from the Max Planck Institute for Ornithology in Seewiesen and Andechs, describing the solicitous coucal father. In the meantime, the female lays more eggs for another of her mates or tries to attract further males. This kind of mating system is called classical polyandry.

Similar to changes in the concentration of testosterone in the blood, the androgen receptors in males and females in such species. Only those of males.

These idiosyncrasies made the African black coucal an ideal model for Wolfgang Goymann and his colleague Cornelia Voigt to investigate how hormones modulate territorial aggression in females. When male birds establish and defend a territory and try to attract females, their gonads secrete increased amounts of testosterone. It would seem reasonable, then, to suppose that exchanging gender roles goes hand in hand with reversal of the testosterone concentration in the blood.

However, females of all classically polyandrous bird species investigated so far – the Wilson’s phalanger, the spotted sandpiper and the African black coucal discussed here – express normal levels of testosterone: high in males, low in females. Nevertheless, the Max Planck researchers have discovered that this “male” hormone could still play a role in controlling aggressive behavior in classically polyandrous females.

Testosterone works by binding to what are known as androgen receptors. These then trigger a gene cascade which, in turn, influences the behavior. “Similar to changes in the concentration of testosterone in the blood, the androgen receptor represents another switch to regulate potential effects of testosterone,” explains Goymann. Rather than increasing the production of the hormone, the organism could instead increase the number and density of the docking sites for testosterone. This may have the same effect on the behavior, and it appears as if this could be exactly what female black coucals do.

The two ornithologists demonstrated that, compared to males, female black coucals express more androgen receptors in the Nucleus taeniae – an area of the brain that is involved in controlling territorial and aggressive behavior. Not only do females have more androgen receptor expressing cells in this area of their brain, but in addition, each individual cell expresses more receptors than do those of males.

“This means that female black coucals could be more sensitive to smaller amounts of testosterone than are males,” explains Cornelia Voigt. This would make sense, because high concentrations of testosterone may prevent reproduction in female vertebrates. “By locally increasing the sensitivity for testosterone in the Nucleus taeniae, female black coucals may be able to avoid the disadvantages of elevated testosterone concentrations,” explains Goymann. “In this way, testosterone may be able to influence aggressive behavior without having confounding effects on the reproductive physiology.”

These findings represent the first indications of a potential physiological mechanism for the sex role reversal in territorial and aggressive behavior. Interestingly, there is no comparative data for birds or other vertebrates with traditional sex roles – a surprising fact for Goymann: “No one has yet compared the expression of androgen receptors in males and females in such species. Only males have been examined, while females received little attention. If our idea is correct, we would expect that females of species with more traditional sex roles should express lower levels of androgen receptors in the Nucleus taeniae. The crucial test of our idea is thus still missing.”

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Cosmology

A Bridge to the Big Bang

The beginnings of the universe bring Albert Einstein to the limits of his knowledge – the laws of the general theory of relativity, which describe the universe on a large scale, do not apply to the Big Bang. In fact, at its beginning, the cosmos followed the laws of quantum gravity: space and time behaved in accordance with the same quantum laws as the tiniest particles.

However, researchers at the Max Planck Institute for Physics in Munich have now found a new way to bridge these two theories. (Physical Review Letters, June 25, 2007)

Using a new model based on the framework of string theory, the scientists described how space and time developed in the first fractions of a second following the Big Bang. Their results show the way in which the universe moved from the quantum gravity phase to the era of the standard model of cosmology, as described by the theory of relativity.

At the birth of the cosmos, matter was infinite-ly dense and space-time curved infinitely into a single point. This singularity is the starting point for a theory of quantum gravity – which is where the Max Planck scientists in Munich began their work. The essential ingredient of their approach is the concept of a fuzzy space-time, as delivered by quantum gravity models. “This is why the universe seems rather shrouded just after the Big Bang,” says project head Johanna Erdmenger. Consequently, it is not possible to determine the space and time coordinates of a point at the same time, and as a result, space-time itself is fuzzy and blurred. “The classical theory cannot be applied to fuzzy space-time,” explains Erdmenger. She and her colleagues have used a new model to explain how classical space-time developed from this fuzzy quantum space-time with the help of string theory. “According to our model, the fuzziness of space-time in the expanding universe diminished extremely quickly,” she says. Her calculations, and those of her team, approached the Big Bang to within a fraction of a second.

This theory does not describe the elementary particles as point-like objects, but as tiny vibrating strings. These strings can be closed or open. Closed strings are similar to a tiny rubber band, and open strings can be compared to violin strings under tension. The points to which these are attached are themselves objects that move in space-time and describe particles.

Physicists call them Dirichlet branes (D-branes). The researchers used open strings and D-branes to explain the nature of space-time close to the Big Bang. To do this, they used the Robertson Walker metric, which describes the expansion of the universe in relation to time.

As the Robertson Walker solution is the same at every point and in every direction, it describes a homogeneous and isotropic universe. In their model, the Munich-based physicists covered the Robertson Walker space-time with an imaginary network consisting of an infinite number of D-branes, and connected them to each other with open strings.

Erdmenger’s team has now shown that, close to the Big Bang, the positions of the D-branes in the network could not all be determined simultaneously – which means that the standard model for cosmology does not work here. However, their model did reveal that this fuzziness rapidly decreases as the radius of the universe grows. Therefore, just shortly after the Big Bang, space obeyed the laws of the general theory of relativity again.

The new model just may be able to explain why astronomers have been examining images from the Hubble Space Telescope without finding the blurring that is supposed to occur with quantum mechanical fuzziness. These effects were apparent only fractions of a second after the Big Bang – and no telescope has yet been able to penetrate as far back as this period.

Atmospheric Chemistry

Mercury from the Rain Forest

Rain forests are polluting the atmosphere with mercury – when they burn. Researchers at the Max Planck Institute for Chemistry in Mainz, and at the GKSS Research Center in Geesthacht, have measured elevated mercury concentra-tions in the smoke from large forest fires in South America. According to these investiga-tions, during the burning season, the forest fires release considerably more mercury than industrial sources in the southern hemisphere. (Geophysical Research Letters, April 2007)

There have always been traces of mercury in the atmosphere, which is how it accumulated in coal millions of years ago. Now, coal-fired power sta-tions, smelters and heating systems are releasing this toxic heavy metal again. It also escapes where garbage is incinerated. Scientists based in Mainz and Geesthacht have now identified yet another significant source of mercury using the CARIBIC air observation system as it flew over a LatinAmerican Airbus from Frankfurt to Santiago de Chile via São Paulo: the burning rain forests in the southern hemisphere.

During the forest fire season from August to October, the fires emit even more mercury than is emitted from burning coal and garbage, or even from gold mining in the southern hemisphere. From the CARIBIC measurements, the researchers have calculated that up to 750 tons of mercury, or 11 percent of all mercury emissions, enter the atmosphere of the southern hemisphere with the forest fires – possibly more than from the anthropogenic sources. “Measurements in the plumes of biomass burning in Canada, for example, have indicated this,” says Slemr. The suspicion also arose because 90 percent of all biomass burning occurs in the southern hemisphere.

Most mercury in the atmosphere occurs as an element vapor; it oxidizes very slowly to form non-volatile and water-soluble compounds that the rain washes out of the air. This is how it gets into lakes and oceans, where it is sometimes converted into the extremely toxic methyl mercury, which then accumulates in the aquatic food chain.

In some types of fish at the end of the aquatic food chain, such as tuna and pike, the methyl mercury concentrations are already at harmful levels. In Canada and Scandinavia, thousands of lakes are so polluted that pregnant women are warned to no longer eat the fish from them. And ocean fish, such as tuna and shark, should not be eaten frequently.

Since forest fires re-mobilize the mercury that the rain has already deposited from the atmosphere, they are making global pollution worse. “The cycle can only be broken by curbing emissions,” says Franz Slemr.
Flower organs in many higher plants are organized in four whorls according to the same pattern: first come the green sepals, which protect the petals that are designed to attract insects or other pollinators. The stamens with their pollen sacs and the carpels, which later develop into a fruit and seeds, are hidden inside the flower. An entire orchestra of genes must be in tune to allow a flower to develop into this ordered structure. Scientists at the Max Planck Institute for Plant Breeding Research in Cologne working with colleagues from Nijmegen have now discovered that microRNA plays a key role in the formation of flower organs. (Nature Genetics, July 2007).

Unlike messenger RNAs (mRNAs), microRNAs consist of fewer than 22 nucleotides. They control the expression of genes by binding to complementary sections of an mRNA that are created when a gene is transcribed. Due to cleavage of the mRNA, or interference with its translation after microRNA binding, it is no longer possible to manufacture the relevant protein. In this way, various microRNAs regulate the development and metabolism of plants and animals.

Mutants for microRNAs are rare, yet researchers in Cologne and their Dutch colleagues obtained a petunia mutant and a petunia mutant in which a gene coding for related miRNAs had been modified. As a consequence, the mutants form petals instead of stamens. “In both of these mutants, the basic order has become confused, causing the wrong organs to grow in the wrong place,” explains the head of the working group, Zsuzsanna Schwarz-Sommer.

How is this microRNA involved in the development of the flower? The control of the identity of the four floral organ types is usually explained in textbooks with the help of the simplified ABC model. According to this model, different control genes are classified into three groups, A, B, and C. Type A genes control the development of the sepals, interaction between groups A and B produces the petals, while the stamens form from the simultaneous expression of groups B and C. The carpels are determined by group C on its own, A, B, and C genes are active in distinct, partially overlapping areas of the flower, and the model assumes that A genes, which include the microRNAs examined, prevent the expression of the C genes in the two outer whorls of flower organs.

“The prediction has been refuted by our study,” says Schwarz-Sommer. “Our model corresponds very well to observations made during experiments and also describes the mechanism of chemotaxis in three dimensions,” that is, under real conditions. In open water, it is also possible for a current to change the orientation of the flower development is indeed more temporal and dynamic than spatial. Instead of abolishing C gene expression in the outer whors, the microRNA controls the level of activity of the C genes in their original area of expression in the center of the flower by a fine-tuning mechanism. In the microRNA mutants, the excess of C-gene product is transmitted to daughter cells during cell division, resulting in an outward expansion of the area of C-gene expression – converting petals to stamens.

In the flowers of the petunia and the snapdragon mutants, the “basic order” of the flower is confused by the same genetic defect. As a result, the wrong organs are growing in the wrong place.
The HI virus smuggles its genetic material into the DNA of body cells, mainly that of certain white blood cells. Immune cells produce new pathogens with this blueprint and thereby cause their own demise. Researchers working with Joachim Hauber from the Heinrich Pette Institute in Hamburg and Frank Buchholz from the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden have achieved the first success in cutting HIV genes out of the human genetic material.

Breaking the vicious cycle: After the HI virus has infected a cell (fig. 1), it integrates its genes into the cell genome and is reproduced. The newly cultivated Tre recombinase recognizes the HIV sequence in the cell genome and cuts it out (fig. 2), leaving a host cell without the HIV genome (fig. 3).

“We removed the virus from the cells, which was not previously possible,” said the scientists. To do this, they used genetic engineering to manufacture a recombinase, an enzyme that functions like molecular scissors. 

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Succeeding Outside the Mainstream

Can we learn from the past? When it comes to the future strategies to be adopted by the Max Planck Society, a look back at past successes may well be helpful. How did the Kaiser Wilhelm/Max Planck Society (KWS/MPS) determine the focus of its research, where were the breakthroughs made and which structural requirements yielded such successes as the Nobel Prize in chemistry awarded to Max Planck scientist Gerhard Ertl?

As simple as the questions may appear, they are hard to answer without falling into the traps implicit in conventional methods of evaluation. We are faced here with a historical research problem that has thus far gone largely unaddressed. Therefore, we must limit ourselves to a few examples that have been considered in the course of other research projects or enlarged upon in discussion with colleagues.

Progress is by no means an exclusively cumulative process; it involves rearranging our systems of knowledge. The development of modern quantum and relativity physics is a prime example, with its non-classical concepts of space, time and matter.

Such innovations are often the product, not of spontaneous paradigm shifts, but of the long-term and conflict-ridden amalgamation of heterogeneous bodies of knowledge. Quantum theory, for example, originated with the integration of aspects of knowledge drawn from physics and chemistry: Were it not for electrical engineering, the problem of black body radiation, the starting point for quantum theory, would probably not have acquired such a central role in research in the 1890s.

To identify and resolve the productive internal conflicts between knowledge systems, it is often necessary to adopt a different perspective than that which first triggered the conflict. Such perspectives tend to originate on the periphery of the mainstream rather than at the core. Thus, when the KWI for Chemistry was founded in 1912, radioactivity was initially studied only by a small department headed by Otto Hahn, while issues of organic and inorganic chemistry were the province of large institute departments. However, by the 1920s, research into radioactivity had become the main focus of the institute, and the heads of the department, Otto Hahn and Lise Meitner, ranked among the world leaders in their field.

The long-term, heterogeneous and discontinuous character of scientific progress makes particular demands on the manner in which research is organized, which is not necessarily coincident with the undisputed need to pursue the mainstream. One of the reasons for the success of the KWS/MPS has been its ability to address this challenge more effectively than other research organizations. Examples range from nuclear fission of uranium to the discovery of organometallic catalysts for the polymerization of olefins at the MPI for Coal
Research, which in 1953 led to the development of the low-pressure polyethylene process – a breakthrough that had then-unforeseeable economic consequences. Other notable successes include the establishment of molecular electrophysiology (at the MPI of Biochemistry), the structural definition of ribosomes (at the MPI for Medicine), and the origination of research into both “Bildungsforschung” and lifespan psychology (at the MPI for Human Development). It is evidently in the nature of the MPS to act as a catalyst for the restructuring of knowledge systems.

The traditional image of scientific progress is one of continuous growth within fixed boundaries, with certain exceptions. From this, two types of success can be derived. The first is successful participation in the mainstream, made evident by the impact factor. The second is an individual and pre-eminent achievement often associated with the nature of the knowledge. Such achievements are frequently recognized only when the “new” is no longer new, but has instead become part of the mainstream. Consider the time lag in awarding Ernst Ruska a Nobel Prize for developing the electron microscope.

On the other hand, given the key role played by the restructuring of knowledge in the advancement of science, these criteria for success are inadequate. As long as the function of the MPS is to act as a catalyst for nurturing already-existing innovative research, these criteria for success are inadequate. Of course, in differing ways, this goal may be achieved through the development of a new institute, or through the establishment of a new institute. At the MPI for Human Development, for example, it was his little known dissertation that had the biggest impact in terms of citations, simply because it came closest to the mainstream.

In the right place at the right time

Neither criterion has value as a forecasting tool, for as indicators of a reorientation of knowledge systems, these criteria for success are inadequate. As long as the function of the MPS is to act as a catalyst for the restructuring of knowledge systems, these criteria for success are inadequate. Of course, in differing ways, this goal may be achieved through the development of a new institute, or through the establishment of a new institute. At the MPI for Human Development, for example, it was his little known dissertation that had the biggest impact in terms of citations, simply because it came closest to the mainstream.

Surprising prospects

It is by no means exceptional in the history of successful research choices to take up one of the challenges facing society. It was, for example, the KWS’s decision to establish institutes dedicated to applied basic research, frequently with generous industrial funding. The Institutes for Coal Research, Fiber Chemistry and Leather Research are just three examples. Current examples of applied or potentially applicable basic research being conducted within the MPS include work on international and foreign law, human development, aging, biotechnology, earth systems and, of course, energy.

One strategy adopted in selecting research topics has proven to be particularly promising: the development of new perspectives derived from the study of peripheral research. A recent example in the field of biology was the discovery of the agrobacterium tumefaciens by Josef Schell (MPI for Plant Breeding Research). Schell discovered the genome of a bacterium that was linked to the path of his work on plant tumors. This unexpectedly paved the way for DNA transfers in plants, and thus provided a basis for genetic engineering.

Supporting the restructuring of knowledge systems at an institutional level makes substantial demands on the MPS and its institutes, and their own ability to mutate. Institutional efficiency also implies a capacity to mutate. The institutes working in these fields are able not only to build bridges between what may be described as two cultures, as is happening at the MPI for Human Cognitive and Brain Sciences and the MPI for Evolutionary Anthropology, but also to take advantage of the traditional fragmentation within the humanities themselves. The two art history institutes operated by the MPS in Italy also demonstrate, in differing ways, how to innovate for humanities. A third is still to be derived from established research traditions nested in a privileged cultural environment.

The issue of development processes today plays a vital role at many Max Planck Institutes, from cosmology, developmental biology and brain research to evolutionary anthropology, science history and human development. Research strategies of a kind that universities cannot adopt, and are even long-term, perspective and requires precisely the kind of institutional support that the MPS offers. Just where is such staying power called for? Certainly in research into nuclear fusion along the lines pursued by the MPI for Plasma Physics, the largest center of fusion research in Europe. Back in 1950s, it was anticipated that nuclear fusion would be commercially viable within about 20 years. Today, it is expected, that the utility of such power plants are available.
Valuable cooperation between institutes

Institutional efficiency can also be reflected in the ability of entire institutes to mutate. Outstanding examples here include the KWI/MPI for Coal Research and the Fritz Haber Institute of the MPS, which have consistently reinvented themselves against the backdrop of significant scientific achievements. The history of the Institute for Coal Research began with the problems inherent in processing coal to increase its value, followed by the concept of converting coal directly into electrical energy. However, successes such as the Fischer-Tropsch process of extracting liquid hydrocarbons (1925) and Karl Ziegler’s low-pressure polyethylene process (1953) already mentioned above steered the institute in other directions. The Fritz Haber Institute, too, has successfully shifted its focus on several occasions, with the main emphasis of its work continually dominated by larger issues, such as the search for a comprehensive understanding of catalysis. The 2007 Nobel Prize in chemistry awarded to Gerhard Ertl of the Fritz Haber Institute for his work on catalytic processes shows that staying power has its rewards.

The development of genuine cooperation in or between institutes can be of key importance for the institutional efficiency with which a particular line of research is conducted. Success is dependent on whether there is a clearly defined focus for convergence, whether cooperation is supported by the use of shared research resources or service departments, and whether inter-departmental project groups are endowed with the necessary degree of adaptability. The earth systems research network, to which the MPIs for Chemistry in Mainz, Meteorology in Hamburg and Biogeochemistry in Jena are voluntarily committed, and which also embraces cooperating departments at four or more other institutes, is a prime example of how to efficiently address interdisciplinary issues.

This example also points to another dimension of institutional efficiency: choosing the right scale on which to operate. On the one hand, it generally makes sense to start with smaller, flexible units. Yet on the other hand, out-of-the-ordinary research projects often need to achieve critical mass in order to prevail over mainstream activities.

The MPS, with its specific mission, plays an important role in the academic division of labor in Germany. Its success is substantially dependent on its political freedom to choose its own organizational forms and research topics in the wider field of basic research. However, the MPS also has a niche role at a global level. It will make better use of its structural advantages if, in the future, it becomes an increasingly global player – always provided that it simultaneously manages, internally, to preserve a collective and concerted awareness of its particular task. This, in turn, places a natural limit on its conceivable expansion in the form of a communication horizon, beyond which the Society’s identity is at risk.

One of the future challenges facing the MPS will be the need to heighten its profile as a scientific organization by offering a unique freedom of research – in other words, the opportunity to step outside of the mainstream, combined with guaranteed continuity of research and openness toward new research orientation. Sharpening the profile of the MPS in this way will necessitate greater flexibility in both the internal structures of the institutes and their external relations.

No research plan, however cleverly devised, can succeed without the MPS placing greater emphasis on an internal as well as external awareness of its specific role in the division of research effort. Given that the concept of excellence is now politically charged and becoming increasingly less trenchant as a unique selling proposition of the MPS, public perception of the Society’s particular task will be decisive in determining how successful it is in attracting both resources and young scientists. Thus, internally, the MPS ought to develop a reflective culture oriented toward its role as a catalyst for structural changes in systems of knowledge. Externally, it must be proactive in seeking recognition of this role.

Jürgen Renn is a Director and Horst Kant an academic staff member at the Max Planck Institute for the History of Science.
Stone, bronze and iron: these three materials characterized several millennia of early human cultural history – epochs in which ever-improving tools and everyday items were invented and produced, and in which craft and commerce flourished and promoted the development of advanced civilizations. Even today’s technological civilization is based on the precise knowledge and resourceful application of a number of different materials. And progress in science and technology is ultimately based on gaining deeper insights into the properties of certain substances. Only in this way – as the following articles demonstrate – can new materials be obtained from simple matter.
If you try to open an oyster, you will notice that the shell is extraordinarily stable, even if it looks very delicate,” says Fritz Aldinger, introducing his field of research and his private passion. The Director at the Max Planck Institute for Metals Research used to go diving a lot. He brought back clamshells and sea urchin spines from his travels – and put them under the institute's electron microscope. However, it was not the diving that turned him on to biominerals, Aldinger points out, laughing, “even if that would make a good story.” But without a doubt, the stiff, tough and unusually stable structures that living organisms produce also fascinate him outside the lab.

The materials scientist excitedly pages through a virtual panopticon of extreme biological cases on his laptop, most of which are found in the microcosm of single-celled organisms: “Just look at the fantastic structure of radiolarian skeletons,” he raves. “And they're comprised of amorphous silicon dioxide.” Amorphous means that the silicon and oxygen atoms in the material form a network with no significant order – as is characteristic for glass. So glass is the substance from which radiolarians create their diverse shapes.

In contrast, when sea urchins let their spines grow, they sort calcium, carbon and oxygen atoms into nice, orderly crystals of calcium carbonate, or crystalline calcite. Aldinger shows a microscope image with the fracture site of a sea urchin spine. The circularly symmetric cross-section, with its holes and bridges, reminds the researcher of a gothic church window. But in scientific terms, the key feature occurs on a much smaller scale, explains Fritz Aldinger: “The individual bridges are practically single crystals!” In a single crystal, the atoms organize themselves into a nearly perfect, flawless matrix.

What people need expensive furnaces and energy-wasting high temperatures to do, sea urchins and their friends do in water, essentially at the temperature of bathwater. Fritz Aldinger and Joachim Bill want to copy this refined method of producing biological substances from nature. That is why they use the term bioinspired to describe the strategy they use to search for technologically compatible substances with completely new properties. Bill, a chemist with a post-doctoral lecturing qualification (habilitation), heads a group of some dozen researchers at the institute who are exploring evolution's idea factory.

**CRYSTAL BRICKS AND ORGANIC MORTAR**

However, the Stuttgart-based group is not interested in simply pirating nature, as many natural materials are of hardly any use in terms of technology. “With imaginative games based on knowledge,” says Aldinger, the Max Planck scientists are attempting to modify the tricks of biology. In reality, however, playing means laborious, methodical detail work. The goal is to find methods for elegantly growing a new material in a test tube.
In its shell, the single-celled alga *Emiliania huxleyi* creates art from calcite—what we call it,” explains Aldinger. In the lab, Joachim Bill points to a test tube containing a watery liquid and, lying on the bottom, a platelet. “It looks completely unspectacular,” says the chemist, almost apologetically. “We have here, for another example and important research material for the group is zinc oxide. It allows a wide variety of microscopic and nanoscopic forms and, in addition, is interesting from a technology standpoint as a semiconductor. It can be used to manufacture transparent, electrically conductive layers that function as contacts for light-emitting diodes, solar cells and liquid crystal displays. What is particularly interesting for Aldinger’s team is that zinc is an important trace element in living organisms. A zinc deficiency is thought to make us more susceptible to disease, which zinc tablets promise to remedy. “That is precisely what gave us the idea,” reports Joachim Bill. The key word behind this brainstorm can be found when one carefully reads the packaging for the zinc tablets: histidine. This amino acid, to the researchers, is like a magic key, for it suppresses the otherwise strong metallic taste of zinc oxide. The researchers obtain precise data on the mechanical properties of their new material. Creating new materials is only half the battle. The other half consists in investigating their properties. In this regard, the Stuttgart campus offers Aldinger’s group ideal conditions: it is home to not only the Max Planck Institute for Metals Research, but also the Max Planck Institute for Solid State Research and three universities. “We have here, for example, a very strong Center for Transmission Electron Microscopy,” explains Bill. This technology makes extremely fine details of the nanostructures visible. If a method should nevertheless be found lacking on the campus, Aldinger’s group procures its own technology. It can be used to manufacture transparent, electrically conductive layers that function as contacts for light-emitting diodes, solar cells and liquid crystal displays. In developing a new composite substance. Clams build their nacre shells layer by layer from tiny aragonite crystals, a crystalline form of calcium carbonate. Although these crystals can be only a few micrometers (millions of a meter) long, their cross-sections measure just a few hundred nanometers (billionths of a meter). The clams build these hexagonal crystal platelets almost like bricks, mortaring them with extremely thin layers of an organic “glue.” The fastness of the glue is ensured primarily by proteins, or protein molecules. Nacre owes its layer structure not only to its enormous fracture toughness, but also to its opalescent appearance. The aragonite crystals form relatively transparent calcite layers with a thickness of a few hundred nanometers, which corresponds to the wavelength of visible light. That is why reflected light diffractions in the calcite-protein sandwich as if into thousands of tiny prisms. “Actually, aragonite is a lousy material,” says Aldinger. “But thanks to this layer structure, oyster shells are 3,000 times more resistant to fracture than a single crystal of pure aragonite.” The trick is to quickly stop tiny cracks that want to propagate when the crystals are subjected to mechanical stress. Such a crack makes it no further than the next protein layer, which brings it to an abrupt halt and diverts it. It might even succeed in making headway, on an offset course, in the next layer of aragonite crystals. However, when this happens, the mechanical tension loses much of its energy. “So if you want to destroy the shell, you have to perform a large ‘work of fracture,’” as we call it,” explains Aldinger. In addition, the team in Stuttgart found that if the thickness ratio of the rows of aragonite “bricks” and the organic glue layers has a major impact on the toughness of the clam shells: the protein layer must in any case be as thin as possible. Calcite is not exactly the substance that delights materials scientists, primarily because it is very difficult to combine with other technologically interesting materials. This means that practically all natural biominerals are unsuitable for technological applications. “And it’s always calcium, magnesium, calcium and sulfur,” jokes Fritz Aldinger, “and of course there’s also silicon, a couple of iron ions and a few others.” This is where biomimetics come into play: Scientists can imitate with extremely thin layers of a crystalline form of calcium carbonate, which corresponds to the wavelength of a few hundred nanometers. The aragonite crystals form relative- ly transparent calcite layers with a thickness of a few hundred nanometers, which corresponds to the wavelength of visible light. That is why reflected light diffractions in the calcite-protein sandwich as if into thousands of tiny prisms. In the shell, the single-celled alga *Emiliania huxleyi* creates art from calcite—that’s what we call it,” explains Aldinger. 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Researchers follow this pattern in stacking sandwiches of titanium dioxide and polyethylene.

Nacre is opalescent because it consists of layers of calcite and biopolymers. The Stuttgart-based researchers follow this pattern in stacking sandwiches of titanium dioxide and polyethylene.

The Max Planck scientists produced nanostructures from zinc compounds. In a pure zinc salt solution, the self-organized polymer layer in such surfaces were again prepared with a systematic chart showing which concentrations. In these solutions, the thread-like DNA molecules form the substructure for nanowires made of perfect zinc oxide single crystals. These wires are only around 50 nanometers thick, but to make up for it, they are several hundred times longer than that.

But with the amino acids, it was suddenly possible to create an astounding array of forms in the micrometer and nanometer range – depending on what chemical fine-tuning the researchers applied in their approaches. In hundreds of test series, the Stuttgart group compiled a systematic chart showing which forms grow in various concentrations of the natural amino acids, and the peptides they make up.

It is frequently a curse to have to work with so many parameters,” says Bill, “but with the amino acids, it was a blessing.” The researchers are now able to produce smooth nanolayers from zinc oxide – or hexagonal platelets whose shape is reminiscent of the aragonite crystal in natural nacre. They can even make microsponges grow on the silicon platelets. These resemble the natural microstructures that make the leaf surface of taro plants (Colocasia esculenta) water repellent, right down to their nanoscopic intricacies. And indeed, the synthetic material also causes water to bead up – that is, it causes the famous lotus effect.

Amino acids are rather small biomolecules. However, the ingredients for the magic potions created by the team in Stuttgart also include very large biomolecules, such as sugar or proteins – gelatin, for instance. "The final trick in Joachim Bill’s lab are DNA strands on which we deposit zinc oxide," says Fritz Aldinger. He excitedly shows a microscopic image with a tangle of long threads. In these, the thread-like DNA molecules form the substructure for nanowires made of perfect zinc oxide single crystals. These wires are only around 50 nanometers thick, but to make up for it, they are several hundred times longer than that.

It is precisely the perfection of the single crystals that makes such materials exciting candidates for the building blocks of nanoelectronics of the future. That is why basic research on such semiconductor nanowires is currently booming (see also MAX-PLANCKRESEARCH 4/2005, page 72 ff.). But physicists, who dominate this research field, let their zinc-oxide nanowires grow from heated metal steam in quartz furnaces. This chemical vapor deposition offers multiple design options, but it is technically complex and requires a lot of energy.

The bioinspired method, on the other hand, is so impressive due to its simplicity and the low temperatures. "Here, it really does work in a beaker," says Aldinger. Of course it will take much more basic research before such methods for bioinspired substances can be controlled so well that industry can use them on a large scale. "But it is amazing that these processes do simply occur in a glass," says Aldinger excitedly, "you almost can't even do anything about it."

AMINO ACIDS

ENSURE VARIETY

The Max Planck scientists produced aqueous solutions with zinc salts to imitate the biological environment. Then they added histidine, cysteine and other amino acids in various concentrations. In these solutions, they then laid silicon platelets whose surfaces were again prepared with a self-organized polymer layer in such a way that zinc oxide can accumulate. In a pure zinc salt solution, the zinc oxide would now grow in stalk-like crystals, which are rather boring as far as materials science is concerned. But with the amino acids, it causes the famous lotus effect.

Water repellent like many plants – the sponge-like structure composed of zinc oxide also provides a lotus effect.

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No other material in the electronics industry is handled with such routine as silicon. The industry would like to use this proficiency when computers one day use light to perform their calculations. The only problem is that, to date, there are no viable light sources made of silicon. **Ulrich Gösele**, Director at the Max Planck Institute of Microstructure Physics, and his colleagues have now produced silicon diodes that may also be customized for use in optoelectronics.

Ulrich Gösele's first success initially put him completely off the idea. Back in the mid-1990s, while still at Duke University on the east coast of the US, his team succeeded in making silicon light up, and thus in creating one of the necessary conditions for the electronics that may rule the future. Some scientists, at least, hope that optoelectronics will one day be able to remedy the shortage of space on computer chips. Then photons will take the place of electrons in interacting with bits, and allow even more computing power in very little space.

But that will take a few more years, in any case. In the meantime, physicists and materials scientists are still investigating the tools that photonics offers: photonic crystals, for instance, that conduct light in much the same way that copper conducts electricity. And light sources that can be produced with tried and tested methods — methods such as those the chip industry routinely uses to etch transistors in silicon. Since it is so good at this, it is expected that optoelectronics, too, will use as many silicon components as possible. For this reason, scientists are working on diodes and lasers made from this element.

That's how things were some 17 years ago, too, when Ulrich Gösele first examined the special optical properties of extremely small silicon structures. “We had used electro-chemical means to etch tiny, unordered structures in a silicon block. Actually, in doing so, we investigated how nanostructures can be produced with this method,” says the physicist: “It was more or less by chance that we then determined that this porous silicon light already begins to absorb in the red range, and not only in the invisible infrared range, like normal silicon.” This indicated that the silicon sponge could also produce visible light. Unfortunately, optical fibers do not conduct visible light particularly well, so a silicon sponge that glows red is not very interesting for the chip industry. In addition, the silicon sponge ages and gradually loses its luminescence — but at least they were on to something.

However, the article that we submitted to Applied Physics Letters on this was initially rejected by a reviewer,” recalls Gösele. So he and his colleagues were all the more surprised when, a few months later, a very similar article appeared in precisely this magazine — published by a British group and waved through by another reviewer. “So I filed a complaint,” says Gösele, his voice unwavering. And thus his silicon sponge became public, too, although a few months after the British publication.

**New Materials**

An oven for very special baked goods: Vadim Talalaev (left) and Andreas Langner heat up nanostructured materials in this device.

**Playing Hardball**

Since Ulrich Gösele’s team had submitted their paper first, it wanted to at least secure the patent. This was in line with applicable law, but not with the interests of the British Ministry of Defense, which had financed the competing article. The Ministry filed a lawsuit to rescind the patent for the silicon sponge: “Their attorneys really played hardball,” says Gösele with an almost apologetic smile: “If you can’t stick it out, you’re ruined.” He gave up the patent that had already been granted.
The Max Planck researcher describes the temporary end of the story: “That frustrated me so much that I initially just steered clear of the whole subject.” Temporary because, more than 10 years later, Ulrich Gisele and his colleagues have indeed taken up the subject again at the Max Planck Institute in Halle. “This research has slacked a bit in the intervening time – and not just for us,” says Gisele: “But it is now booming again.” The fact is that there is, as yet, no industrially usable silicon dioxide, or even a silicon laser that the chip industry could feasibly use in optoelectronics. This is due primarily to the fact that, from a physical standpoint, silicon is far from being the material of choice for a light source. In order for a material to emit light, its electrons must first take up energy, which can be supplied to them in the form of, for instance, electrical energy. When this happens, they jump from a lower energy level to a higher one – with a kind of energy springboard. From there, they fall back to the lower level and release their excess energy, in the best case as light, or in physical terms, as photons.

Today’s printed circuit board: Here, data still travels through the circuits as small pulses of electricity. In the future, pulses of light could transport the bits.

With a semiconductor such as silicon, this is slightly different: When one of its electrons is excited, for example by electricity, as in a diode, or by light, as in a solar cell, it not only leaves its excited level, but also its atom. It falls in with the herd of electrons that conduct electricity in a semiconductor, and belongs to all atoms, and to none. It leaves a hole in its original atom, creating a positive charge there. However, the electron of an adjacent atom quickly fills this hole, so the hole, too, is essentially distributed across the entire piece of silicon. Now, if an excited electron releases its energy again, it falls into one of the holes.

One requirement for the electron jump is that the energy levels – energy bands, in the case of a metal (see box) – lie favorably. Favorably means that the electron must wander through the metal with the same momentum before and after the jump. Put simply, it must not change its speed or the orientation of its orbit while it takes up and releases energy. Quantum mechanics prohibits this, and this applies to both the upward and the downward jump.

Too bad for the optoelectronics specialists that the energy bands don’t lie appropriately in a piece of pure silicon. Physicists say that it exhibits an indirect band gap because the lowest point of the upper bands does not lie where the lower one reaches its highest point. Since the electrons had to change their momentum when jumping between these bands, their jump is negligible – and silicon doesn’t light up.

**A Silicon and Germanium Sandwich**

But physicists are trying to change this. The indirect band gap, Peter Werner, Vadim Talalaev and their colleagues at the Max Planck Institute in Halle have mastered the tricks that help the silicon electrons jump. For example, the researchers recently constructed a light-emitting diode based on semiconductors. Silicon, however, is just one component in it: as in a sandwich, the scientists alternated nano-meter-thin layers of silicon with a dash of antimony and germanium, stacked one on top of another. Such a sandwich structure is called a superlattice because a second array lies above the crystal lattice of the semiconductor. The germanium-silicon superlattice lights up because, in the adjacent germanium layers, the electrons of the silicon find suitable holes into which they can fall, creating a luminous trail.

Before Vadim Talalaev enters the lab in which he and his colleagues stack the semiconductors to form such “sandwiches,” he slips blue plastic covers over his shoes. Considering that scrupulous cleanliness is crucial for the room where the scientists stack silicon and germanium into superlattices (even atomic dirt can extinguish the diodes’ light), that is a very modest effort to keep the room clean. That is also why the equipment in the middle of the room is surrounded by a heavy curtain made of transparent plastic strips the width of a hand, behind which an extractor sucks dust and lint out of the air.

This is where the tail system for molecular beam epitaxy stands. Two steel chambers, one of which, with its observation window, is reminiscent of a diving bell. Except that it is studied all around with cables and metal poles of varying thicknesses. In front of one side sits the second cylinder-shaped chamber like the boiler of a steam engine. This is where the physicists feed the wafers, shiny disks of silicon, into the equipment.

After the pumps at the foot of the system have suctioned the air out of the lock for several hours, at the physicist’s command, a gripper arm ma-neuvers the silicon disks into the main chamber. An ultrahigh vacuum is at work here, which means that only a few hundred million molecules are zipping through the container. While that may still sound like a lot, it is billions of times less than the number we draw in with each breath. The researchers now alternately evaporate silicon, antimony and germanium from various crucibles. At the same time, they cool the silicon disk so that the gaseous substances condense on it. Estimating when the layer has precisely the right thickness is part of the art of experimenting. At least calibration curves offer the scientists a guide to how much of a certain material builds up in how much time.

The layers of germanium must not exceed a thickness of five nanometers, on average, and those of silicon not much more, in order for the superlattice to light up. Such a thin germanium layer forms a quantum dot whose electronic properties resemble those of an individual atom (see box). "The quantum effects that occur in the nanometer range make this research quite interesting for us," says Ulrich Gisele.

One of the effects is that the electrons of adjacent silicon layers tunnel through the germanium layer that separates them. In doing so, they perform the same feat that allows Harry Potter and his fellow wizards to access platform 9 3/4, where the Hogwarts Express picks them up to take them to wizard school: they pass through a wall that we would bounce off of like a rubber ball. After all, we can neither perform magic nor are we small enough that the laws of quantum mechanics apply to us.

**Miniband Makes Superlattices Luminesce**

The tunnel effect is what makes the silicon-germanium superlattice a visible light source. Sandwiches made of thicker layers of both semiconductors also light up, but only very weakly because it is difficult for the electrons to reach the holes in the germanium. Unlike in a superlattice made of nanometer-thin layers: because the silicon layers find each other here by tunneling, they form an energy band that also extends across the germanium layers. Physicists call this a miniband, to distinguish it from the normal bands in the metalls. “The miniband of the silicon lies in such a way that its electrons can easily jump from silicon to germanium,” says Talalaev. In doing so, they release energy – and the superlattice lights up.

And it lights up quite well. “One diode from our silicon-germanium superlattice achieves a quantum efficiency of 0.04 percent for infrared light," says Talalaev. The quantum efficiency indicates how efficiently the diode converts electricity to light. Although 0.04 percent is just one-twentieth of the efficiency achieved by light-emitting diodes in a flat screen display, it is already 100 times more efficient than other nanodiodes composed of silicon and germanium. It was also by coincidence that the physicists in Halle discovered that minibands form in stacks of thin germanium and silicon layers and thus boost the luminosity of the germanium quantum dots: they had actually wanted to produce germanium quantum dots that are even thinner than the germanium layers in their diodes – but most importantly, they were to be kept at a distance from...
considerably thicker silicon layers. “Then we vapor deposited the germanium layers a bit too thickly and the silicon layers too thinly,” says Peter Werner. Nevertheless, the scientists measured the luminosity of the silicon-germanium sandwiches – and were surprised by the result: the superlattice was much more luminous than a stack with insulated germanium quantum dots. And unlike the latter, there was still light even at room temperature. “We have since gathered a lot of evidence to show that minibands form in the superlattice that improve quantum efficiency,” says Werner. Other physicists had long doubted this because the effect was previously known only from gallium arsenide and indium gallium arsenide.

**Antimony Mediates between the Elements**

The Max Planck researchers have now devoted themselves to systematically investigating the phenomenon and further optimized the diode until they had the recently presented diode comprised of 20 layers of each of the semiconductors. In doing so, they found yet another trick for boosting the luminosity of their diodes: they doped the silicon layers with antimony by covering the germanium quantum dots with an atomic layer of this material. This brought them not just one, but two advantages: first, there are free electrons dancing around in the outer shell of antimony atoms (which is chemically related to arsenic), rather than just four, as in silicon. In contact with silicon atoms, these additional electrons increase the electrical activity of the material – there are simply more electrons available to produce light.

“Second, at the boundary between silicon and germanium, antimony acts like a tensile,” says Talalayev. So it mediates between the two elements by reducing the surface tension between them. The atoms of the silicon cannot, in fact, be stacked neatly on top of the germanium atoms because their crystal lattice is somewhat smaller. Without antimony, the arrangement of the silicon continually gets disarranged and cracks appear. The electrons that want to jump from the silicon to the germanium then tend to fall into the cracks. When this happens, they do not emit light – that is, their quantum efficiency decreases. Rather, their energy is released as heat. The antimony layer mediates between silicon and germanium in such a way that they positively cling to each other. As a result, far fewer excited atoms are lost at the boundary of the two semiconductors, and the quantum efficiency increases. This method is now even protected by a US patent: “A semiconductor diode with our efficiency would be sufficient for optoelectronics,” says Talalayev. But for potential applications, it would be better if the material could be used to build, not a mere light-emitting diode, but a laser. Many scientists around the world are working on such “laser dots,” as researchers at the University of California Los Angeles recently processed silicon into such a bright light source for the first time. But they need another laser to supply the silicon laser with energy, or to pump it, as it is called in the field,” says Ulrich Gösele. The pump laser supplies the silicon with the energy it needs to produce light of this quality itself. “I don’t believe that has any future for applications,” says Gösele.

**Inspired during a Lecture**

What would be far more practical is a silicon laser that draws its energy directly from a solar cell or a battery – in other words, a laser diode. The scientists at the Max Planck Institute of Microstructure Physics already have a silicon-based diode in the form of their superlattice. “Now we are trying to build a laser from it,” says Vadim Talalayev. In theory, that is possible. However, in terms of the details, it is not easy to trap the light of the silicon-germanium superlattice between mirrors in such a way that it is amplified into a laser beam. An engineer is now trying to help the physicists equip the silicon-germanium sandwiches with mirrors and contacts.

“To construct optoelectronic components from this material, we had to produce it with a different method than molecular beam epitaxy,” says Ulrich Gösele. This method is time consuming and expensive. Furthermore, the scientists would have to make it light up more intensely. Lorenzo Pavesi, at least, is convinced of this. Pavesi teaches and conducts research at the University of Trento in northern Italy. His goal, too, is to build lasers based on silicon and he uses, among other things, silicon nanocrystals as the active medium. He is also trying to use silicon nanocrystals to build lasers like those Margit Zacharias produces.

Until recently, Zacharias headed a research group in Ulrich Gösele’s department. She has now been appointed professor at the University of Freiburg (Max-Planck-Research 2004/5, p. 72ff.). In a block of silicon dioxide, her silicon nanocrystals arrange themselves into a pattern that, in transmission electron microscopy images, looks like a Belgian waffle. But actually the comparison with a waffle is more fitting, as the nanocrystals sit in the silicon dioxide like the cherries in the torte – just a lot more orderly, forming, in turn, a superlattice of quantum dots. Layer by layer, silicon nanocrystals line up next to one another in a regular arrangement, surrounded by a silicon dioxide shell.

In any case, the image of tortes and waffles is fitting in that the manufacturing does have something to do with baking. It is called tempering in the jargon of the materials scientists, but it means nothing more than heating a substance in the furnace. The idea that a superlattice of nanocrystals could be produced in this way came to Margit Zacharias in November 2001 during a conference in the US: “I was sitting in a rather boring lecture and my mind wandered,” relates the scientist.

**Heat Helps with Arranging**

So they concocted the recipe for the nanocrystal torte: First spread on a firm layer of silicon dioxide. Then vapor deposit a mixed oxide that likewise contains silicon and oxygen, but not quite in the same ratio as silicon dioxide. Cover that with another layer of silicon dioxide and repeat the entire procedure as often as desired. Thereafter, the layers of the two oxides should bake for about an hour in a furnace heated to 1,100 degrees Celsius. The silicon dioxide shouldn’t change in the heat, but the mixed oxide – so Margit Zacharias imagined – should separate into regions of pure crystalline silicon and spots such as silicon – a viable light source.
of silicon dioxide. Neither the oxygen nor the silicon feels chemically “at home” in the mixed oxide, and the heat in the furnace would give them the energy to rearrange themselves as needed. When Margit Zacharias, back in Halle, presented the recipe to her then-boss, Ulrich Gosele, he was immediately convinced: “Don’t tell anyone about this,” he said to her. There was too great a risk that someone would pick up her recipe and be able to implement it faster. “I immediately sat down, wrote down the idea and got the signatures of two witnesses to attest to it,” adds Margit Zacharias.

The scientist was, in fact, the first to realize her creation of silicon nanocrystals. Not only do the silicon crystals form exactly the way she imagined it – they are all nice and round, nearly the same size, and they line up in orderly rows. “We can even control the spacing of the crystals in the layer through the oxygen percentage,” says the physicist: “And that’s why they can find each other more easily and emit a flash of light when they meet. How tiny the crystals are also determines what color the quantum dots luminesce: crystals measuring two nanometers emit orange-red light, and if they measure four nanometers, they radiate in the near infrared.

It is again a quantum effect to which the nanocrystals owe their luminescence – quantum confinement. Regardless of whether one nanometer or four, all of the crystals are so tiny that their electrons and holes no longer have much freedom of movement. So little, in fact, that it is possible to precisely determine their location. Quantum mechanics comes into play here, which is also the reason why the nanocrystals are quantum dots. If they tunnel through the silicon dioxide layer, they can find each other.”

Furthermore, they must simultaneously bring the charge carriers into the quantum dots so that they unite with a flash of light. If they tunnel into the crystals in succession, they quickly disappear into the imperfectly formed surface of the nanocrystals. But Pavesi already has some ideas for solving these problems. “Of course I can’t reveal how we intend to do that,” he says: “But it looks promising.”

Margit Zacharias is not quite as optimistic: “We have had only contradictory results so far on whether the nanocrystals are suitable for a laser,” she says: “But I am no longer following this topic now because I am more interested in the charge storage possibilities at the moment.” So Margit Zacharias has already identified another potential use for the nanocrystals: as storage nodes in conventional electronics. Then it wouldn’t matter whether physics continues to resist a viable silicon light.

FOCUS

Talalaev (from left) from the Max Planck Institute of Microstructure Physics get into a discussion.

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Here, too, the size of the crystals is key. “Sometimes I imagine that the electrons and the holes in the nanocrystals simply can’t avoid each other,” says Margit Zacharias. That’s why they can find each other more easily and emit a flash of light when they meet. How tiny the crystals are also determines what color the quantum dots luminesce: crystals measuring two nanometers emit orange-red light, and if they measure four nanometers, they radiate in the near infrared.

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The Metal Sets the Tone

New materials can be pretty old – the alloys developed by Brigitte Baretzky and her team at the Max Planck Institute for Metals Research are proof of that. To enable organ builders to faithfully restore old instruments, the scientists are using modern methods to study how baroque organ builders made the metal that went into their pipes.

The bulky building on the west side of the city of Stuttgart is not exactly beautiful to behold. Even the sober office – white walls, desk and monitor – on the third floor of the Max Planck Institute for Metals Research yields no clue to the fact that the work done here is concerned with the fine arts. This is where Brigitte Baretzky works as head of the nanostructures at interfaces research group in Gisela Schütz’s department. For the past three years, she has been using modern methods from the fields of physics and materials science in an attempt to uncover the secrets of the organ builders of the baroque period.

When Brigitte Baretzky – every bit the scientific manager – talks on the phone about research schools, financing and subprojects, she reveals nothing of the passion and fire with which she later talks about baroque organ music. Her voice takes on an enthusiastic character as she speaks about the Casparini organ in the Church of the Holy Spirit in Vilnius, Lithuania, or the artistry of other baroque organ builders. For decades, subsequent organ builders did not attain this level of refinement as baroque craftsmanship largely faded into obscurity in the 19th and 20th centuries.

Asked what is so special about the sound, Brigitte Baretzky effusively replies: “It’s like the difference between a Stradivarius and a cheap Japanese mass-produced violin. Or like eating out at a top restaurant and then going to the university cafeteria the next day.”

The way a reed pipe works is completely different. The flow of air causes a brass lamella just a few tenths of a millimeter thick to vibrate: this is the tongue, reed, that gives the pipe its name. The tongue vibrates above a brass groove called a shallot, producing a note. Short, thin tongues produce high notes; long, thick tongues produce low notes. A resonator amplifies the note. The resonator is visual inspection of the Casparini organ (left) yielded little of the secrets of its sound to Brigitte Baretzky and Lithuanian organ builder Rimantas Guras. The organ was restored with the help of materials scientists as part of the Truesound project.
And not only to answer the question: "How did they do this in the past?" What the researchers were really interested in was using the knowledge gained from Truesound and an earli-er project to enable organ builders to properly restore and repair historic organs, such as the Caparini organ. As a result, they managed to give or-gan builders the means to install a vox humana stop in this organ – an important reed stop that replicates the human voice, but that no longer existed in the instrument in Vilnius. Brigitte Baretzky was brought into the organ project by Russian scien-tist Boris Strausmal and Milan Friesel, a materials scientist from Chalmers University in Gothenburg. Boris Strausmal told her about the project and asked if she’d like to get in- volved. "Initially, I was really surprised and wondered what organ pipes had to do with materials re-search," says Baretzky.

**EXPERIMENTAL TRICKS REVEAL SOUND SECRETS**

That was in early 2003. By the time the researchers applied for funding from the European Commission in October 2003, she had realized that there was a great deal of materials research behind the secrets of baroque-era organ building. In No-vember 2004, working with teams from a total of four research insti-tutes based in Stuttgart (Germany), Gothenburg (Sweden) and Ancona (Italy), as well as five organ builders from Italy, Sweden, the Netherlands, Latvia and Lithuania, Brigitte Baretzky embarked on the quest for the lost sound.

The researchers examined reed pipes of around thirty historic organs from nine European countries, rang-ing from Italy and Germany to Eng-land and the Baltic States. And it was a relatively simple, centuries-old experimental technology – namely light microscopy - that revealed the existence of significant variations in grain size between the pipes in dif-ferent organs, but these did not re-sult in any audible discrepancies. This was obviously not the key to unlocking the secret of the sound. To find the key, Brigitte Baretzky and her fellow researchers had to delve a little deeper into their box of experimental tricks. They examined the pipes using X-ray and neutron diffraction, as well as electron probe microscopy. They also used secondary ion mass spectrometry (SIMS) and a special form of optical emission spec-troscopy to trace the secret of the sound. These methods were used to analyze just how much of which ele-ments a given material contains, and how the elements are arranged. How-ever, the methods differ substantially in their sensitivity; their accuracy de-pends dramatically on whether the ele-ments to be verified are present in large quantities or in trace form only. They also require different sample sizes and thicknesses.

The fact that the objects in the Truesound experiments were parts of historical reed pipes presented a challenge all its own. The materials scientists had to avoid damaging or, worse still, destroying the tongues and shallots while taking their mea-surements. For the X-ray and neu-tron diffraction experiments, the sci-entists carefully removed the tongues and shallots from the organs. They then took the entire pieces to the ac-celerator providing the radiation for the X-ray and neutron diffraction and mounted them inside.

For the electron probe microanaly-sis and the light microscopy, they cut tiny pieces measuring one to two millimeters square out of the non- vi-brating parts of the tongue – in other words, the parts not directly respon-sible for the sound of the pipe. Only occasionally, if the tongue was al-ready damaged, did they cut off larger samples, which they examined with a transmission electron micro-scope. And, of course, they took samples only from some, not all, of the reed pipes in an organ.

The researchers determined the composition of the tongues and shallots and identified the concentration of the main components, namely copper, zinc and lead. The concen-tration of other elements, such as iron, manganese, nickel and tin, was less than one percent each, which is below their respective solubility limit in copper. These metals could there-fore be considered impurities, mean-ing that the scientists could ignore them for the purpose of developing new alloys.

What really interested the re-searchers was how the zinc and lead content was dependent on the year the organs were built. They recorded the results of their analyses in charts, noting the year each instrument was constructed – and received a sur prise. The curve for both the zinc and the lead concentration presented them with a puzzle.

The zinc concentration remained almost constant at 26 weight percent until the year 1740. Then it jumped to more than 32 weight percent. Yet, zinc is soluble in copper. In 1760, the weight per-cent continued to be used in organ building for about another fifty years. What was behind this sudden step? It must have been related to the way brass was produced. Brigitte Baretzky and her team unraveled the mystery by taking a look back at the history of metallurgy.

Making brass, an alloy of copper and zinc, should – one would think – be so simple. Copper is melt-ed, then zinc is melted and ... unfor-tunately, back in the early 18th cen-tury, it was not quite that easy. Up until 1738, zinc was available only in the form of calamine (a carbonate of zinc) or zinc oxide. Metallurgists produced brass by a process called cementation. Pieces of copper, coal and calamine were put into a pot and heated – to a temperature above the boiling point of zinc, which is around 907 degrees Celsius, but below the melting point of copper at 1,083 degrees Celsius. The calamine was thus reduced, the resulting ele-mental zinc evaporated and immedi-ately diffused from the gas phase into the hot but still solid copper.

**MYSTERIOUS LEAD CONTENT**

To avoid consuming too much coal, the metal makers of the 18th century kept the temperature just above 907 degrees Celsius. It probably reached about 920 degrees Celsius at this temperature, 26 weight percent of zinc is soluble in copper. In 1738, a British inventor took out a patent on a method for producing metallic zinc. This was then blended with copper to make brass. As a result, up to 35 weight percent of zinc became soluble in copper. The concentration of lead posed another riddle for the scientists. Did it...
Örgryte Nya Kyrka in Gothenburg sounds like an instrument from the heyday of organ building.

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look at the lead concentration of production of organ brass differs alloy of copper and tin. Although the production.

Baretzky found an important clue in special, as yet unknown properties? material failure.

Without annealing, the lead causes internal stresses and can lead to material failure.

But did the organ builders intentionally add lead to the brass due to special, as yet unknown properties? The scientists working with Brigitte Baretzky found an important clue in a field that has absolutely nothing to do with organ building: cannon production.

Cannons were cast in bronze, an alloy of copper and tin. Although the production of organ brass differs fundamentally from the production of cannon bronze, it is very useful to look at the lead concentration of cannons manufactured at the same time and in the same regions as the organ pipes investigated in the True- sound project. Cannon bronze from around the year 1600 contains about 7 weight percent of lead, falling to 2 weight percent in the period until 1750, before plummeting to almost zero. “If these two fundamentally different processes are compared and one considers that the lead concentra- tion behaves exactly the same over time, then it becomes clear that the lead was not intentionally added: it was already present in the copper and was to some extent a necessary evil,” concludes Brigitte Baretzky. In order to faithfully reproduce the organ pipes from the 17th and early 18th centuries, the Truesound scien- tists added another 2 weight percent of lead to the brass containing 25 weight percent of zinc. For organs from the late 18th and the 19th cen- turies, they developed a lead-free brass with 30 weight percent of zinc. They also determined the key steps in the manufacturing process: a sophisti- cated interplay of mechanical processing by casting, forming, ham- mering, rolling and filing on the one hand, and annealing on the other. The second of these two recipes was applied in Vilius, where the vox humana stop was reproduced in the Casparini organ in the Church of the Holy Spirit. Professor Harald Vogel from Bremen gave a concert on October 14, 2006 to inaugurate the reed pipe stop. In his opinion, the combination of organ building and materials research has resulted in an extremely fruitful collaboration: “The spectrum of timbres has been very well extended by the new vox humana stop.”

Harald Vogel has also played an organ that was not merely restored, but completely built in the baroque style using the findings from the Truesound project: the organ in the Örgyte Nya Kyrka in Gothenburg, Sweden. Here, too, his verdict re- flects his excitement: “The organ has an outstanding sound. We have defi- nitely come a step closer to the historical act of organ building. The Truesound project is a boon for historical music.”

NEW INSIGHTS RAISE NEW QUESTIONS

The Truesound project is currently in its final phase. But even now, the scientists are still solving riddles posed by the pipe metal: investiga- tions with a high-resolution transmission electron microscope initially seemed to indicate that the copper and zinc atoms in the brass of a 300-year-old, naturally aged tongue had arranged themselves into an ordered crystal structure within certain boundaries.

In the meantime, the scientists have come to the conclusion that an ordered structure is definitely pres- ent in the metal. However, it com- prises ordered copper oxide particles of just a few nanometers in size. “What happened here is what we call internal oxidation,” explains Brigitte Baretzky. “However, we did find ma- jor variations between the different samples.” The X-ray diffraction ex- periments at the European Synchrotron Radiation Facility in Grenoble brought many new insights, but also some new questions, necessitating further experiments. For instance, the researchers now need to work out what effect the nanoparticles of copper oxide have on the material properties of the brass and the sound of the organ pipes – a problem that has rekindled Brigitte Baretzky’s sci- entific curiosity, her laconic com- ment for the moment being: “That’s something that needs a bit of think- ing about.”

The scientist herself does not play the organ. “But I’ve become an enthusiastic listener,” she says. To her ears, one organ is no longer the same as the next. She cannot listen to the sound of organs with metallic harmonics for very long and speaks confidently of a tuning rich in pri- mary harmonics, which she prefers. Even after the end of Truesound, histor- ical organs will not let her out of their grasp, as the next research proj- ect is already on the agenda. This time, the scientists want to study how flue pipes react to mechanical stress: long pipes with a large diam- eter and relatively thin walls are of- ten unable to hold their own weight over time. The upper part of the pipe presses down on the lower section and causes the pipe to bend in the middle, like a straw. The scientists want to find out why this happens, and how it can best be avoided. Yet another research project that shows just how much organ pipes are a part of materials research.
Trees have no muscles – at least none made of flesh and blood. And yet they hold their own weight and grow up toward the sky. “When branches become boughs, they grow muscle-like wood cells to bear the increase in weight,” says Peter Fratzl, head of the Biomaterials department at the Max Planck Institute of Colloids and Interfaces in Golm near Potsdam. It is these kinds of wood muscles that bend the trunks of mountainside spruce trees to a vertical position, pointing straight up. “We now understand how trees do this,” says the physicist.

With this knowledge, the researchers developed an artificial muscle that is induced to move by a change in air humidity. The discovery was no mere coincidence: the scientists from Golm are systematically searching for inventions of nature – templates technicians can translate into new mechanical drives, microscopically small valves or light yet tough materials. The team members employ a veritable arsenal of lab equipment and mathematical calculation methods in their quest; after all, Mother Nature likes to keep her cards close to her chest.

Peter Fratzl explains why nature’s inventions are so hard to copy: it’s because organisms are way too complex in their construction. Take robots, for example: “They used to walk stiffly and look ungainly,” says Fratzl. “Stiff legs and joints are simply incapable of replicating the smooth gait of a human being.” This only becomes possible with the sophisticated interaction of rigid bones and elastic muscles and tendons.

“Technicians first had to understand the role of the various components in the overall ‘movement machine’ before they were able to build a robot that walked like a man.”

There is another reason why simple duplication is rarely possible. “From an engineer’s perspective, nature does not always offer the best solution,” says Fratzl. For instance, an engineer might want to replicate a bone to come up with a robust yet light material. However, bones are more than just supporting pillars for the body – they also serve as the body’s ion accumulators and bone marrow stores.

“A single biological tissue can have many functions,” says Fratzl. Bones, muscles or branches are multitalent-ed – the answer to the countless problems that assailed the organism in the course of evolution. “What environmental conditions a given tissue had to adapt to during its evolution is something we do not know,” says Fratzl. The Dutch bioengineer Rik Huiskes puts the problem in a nutshell when he says, “If bones are the answer, what was the question?”

WATER GIVES WOOD MUSCLES STRENGTH

The researchers do not even know which of its roles the biological tissue fulfills the best and which are merely satisfied ‘on the side’. To find out, the scientists from the Max Planck Institute in Golm are studying parts of plants, cells and bones under the conditions they encounter in nature: “We are trying to shed light on the essential core of the tissue’s individual functions,” says Fratzl. This will result in functional...
principles that engineers can then modify to create a technical solution that best fits its purpose.

The scientists are now hot on the heels of the functional principle of wood muscles. The cell wall of the tubular wood cells can absorb water like a sponge. What makes this possible is a porous bundle of hemicellulose, a macromolecule similar to cellulose. “The cellulose fibers, which are oriented like cables of a suspension bridge, are embedded in this hemicellulose ‘sponge.’ The fibers are hundreds of thousands of times thinner than a human hair, yet they are extremely rigid and can bear huge weights without stretching. They are about a hundred times stiffer than the surrounding sponge to which they are firmly attached.

The hemicellulose sponge swells as it absorbs water. The crystalline cellulose fibers, on the other hand, do not absorb any water. The direction of the cellulose fibers determines whether the wood cell expands or contracts. Since the wet cellulose fibers do not stretch, the wood cell can expand only in a perpendicular direction. Therefore, if the fibers lie transversely to the branch, the wood cells expand lengthwise along the branch. And if the fibers run parallel to the branch, something different happens: “Although the cells may swell up overall, it contracts in the direction in which the branch is pointing,” says Ingo Burgert, one of the scientists in Peter Fratzl’s department. That’s because of the cell wall organization and the geometrical constraints of the cell. With these kinds of fibers one can thereby pull on the branch. “If the weight a branch has to bear increases, ‘pulling cells’ form on its topside while ‘pushing cells’ form on the underside,” explains Burgert.

The live tree keeps the cells constantly supplied with enough water to maintain their pulling or pushing force. Dead branches, on the other hand, absorb moisture from the air. Man has used this fact since time immemorial as a means of forecast- ing the weather: we nail a twig about the width of a finger onto a board. We then carve the word ‘rain’ into a few centimeters above the end of the twig and the word ‘sun’ just below the twig. If rising levels of humidity herald rain, the cells in the wall will become saturated with water. In this case, the cells on the underside of the twig will expand while those on the topside contract. The twig thus bends upwards several centimeters. Kicking to the Rhythm of Day and Night

The twig does this even though each of the billions of wood cells expands or contracts by no more than a few thousandths of a millimeter. The researchers from Golm observed during their scans that this miniscule change with a high-resolution video camera. And now they want to investigate the cells in more detail. “We want to know how the cellulose fibers change if we stretch the wood cells,” says Burgert. Individual molecules are the building blocks nature uses to construct tissue. We are interested in the correlation between molecular mechanics and the molecular makeup of a tissue.”

To enable them to find this out, the scientists built a type of stretch- ing bank to stretch the individual cells. While the wood cells expand inside the apparatus, the researchers also monitor in Peter Fratzl’s department. That’s because of the cell wall organization and the geometrical constraints of the cell. With these kinds of fibers one can thereby pull on the branch. “If the weight a branch has to bear increases, ‘pulling cells’ form on its topside while ‘pushing cells’ form on the underside,” explains Burgert.

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The twig does this even though each of the billions of wood cells expands or contracts by no more than a few thousandths of a millimeter. While stretching the cell wall, the scientists can measure the stiffness of parts of the plant. And they determine the orientation of the cellulose fibers using X-ray diffraction.

Rivka Elbaum used X-rays to in- vestigate another feat of nature, one outside the bounds of botany: one hair, which falls during the day before rising again at night. The Humboldt fellow’s work at the institute in Golm revealed how granules of wild wheat bore into the earth. The two antenna-like appendages, called awns, are the active parts of the seed dispersal apparatus. “The antennae bend away from each other in the daytime, the awns bend away from each other again to tauten the wheat seed’s inbuilt ratchet once more,” says Fratzl. “It’s the same principle behind the muscle-like wood cells and the mo- bile awns,” says Fratzl. “The cells consist of a stiff, inflexible compo- nent that is embedded in an extensible gel. The two components are firmly connected.”

The drying and shrinking of the gel creates tension in the structure similar to what happens in a network of rubber fibers when they contract. “This tension stores energy and allows the fibers to perform work,” says the physicist.

Engineers can form active materi- als out of different stiff and flexible components. These new composite materials differ fundamentally from the artificial muscles and motors known to date. “Materials and mo- tors are one and the same thing,” says Fratzl. They are not a machine assembled from individual compo- nents. Furthermore, the active ma- terial works on its own without needing to be controlled or operated. “As with the wheat awns, the drive system could be controlled by a daily cycle of air humidity,” says Fratzl. “Although the work the ma-erial did would not be available ar- bitrarily, it wouldn’t cost anything.”

Fratzl can imagine active materials one day being used to turn solar cells to follow the motion of the sun throughout the day, in much the same way as the wood muscles or the awns work. Such artificial muscles would be built along similar principles to the natural models provided by plants, while consisting of a completely different material. In fact, Fratzl thinks they should. After all, in the course of evolution, plants and ani- mals had to make do with just a few raw materials and with whatever environmental conditions they encoun- tered. “Nature cannot make materials out of thin air, for example, because that often requires temperatures of a thousand degrees Celsius,” says the physicist. Engineers, on the oth- er hand, have many more materials at their disposal than a spice finds on a barren mountainside. This is an advantage the researchers at the Max Planck Institute of Col- loids and Interfaces and the Ameri- can firm Bell Laboratories recently took advantage of.

They developed an active material that takes only its underlying principles from plants: it’s made of cellulose, a soft component, firmly connected. For the rigid part, the scientists chose silicon columns thousands of times thinner than a human hair and only a few thousandths of a millimeter long. The flexible component, a hy- drogel, is similar to the gel in plant muscles: it consists of a bundle of synthetic fibers with the ability to absorb water.

Like Reeds in Water

Like the natural gel, this gel swells up dramatically as it absorbs water. The researchers spread the wet hy- drogel over a glass base in a film a few thousandths of a millimeter thick. They put the silicon columns in the gel so that they stood up like reeds in water. Then they heated the sample slightly to bind the columns chemically with the hydrogel and set them fast.

When the gel dries and contracts, the silicon nanocolumns tilt. In do- ing so, they reduce the distance be- tween them, thus yielding to the pull of the shrinking hydrogel. The researchers noticed the formation of areas in which all of the columns lay parallel, like in a field of wheat after heavy rain. “And as you spread the hydrogel thinner, you even get all of the nanocolumns tilting in the same direction,” says Fratzl.
In a humidity chamber, the researchers controlled the water content of the hydrogel, thereby controlling the degree of tilt of the silicon columns. The columns always returned to an upright position when the air humidity reverted to its original level. This is very important for the purposes of technical application: only when a movement is reversible can the new material do a job — otherwise it is just a stuck cog.

Having got their first active material to work, the team of researchers went one step beyond the natural principle. They wondered what would happen if the silicon columns bent. To find out, they created a field full of the nanocolumns firmly attached to a sheet of silicon. Between the columns they spread a thin film of hydrogel, leaving about half of the length of the nanocolumns sticking out.

As the gel dried, the effect was similar to what happens to a thin film of water on a smooth surface: the gel formed droplets to reduce its surface area. Each of the droplets collected between four silicon columns. When the gel dried even more, the pearls of gel shrank and bent the silicon columns toward each other like the jaws of a gripper. And this microscopic grip can be opened as the bent nanocolumns, free to move in the gel, return to an upright position. “Such complex movement patterns cannot be achieved with the artificial muscles created so far, which use electric and magnetic fields to move synthetic parts,” wrote the researchers in the journal Science in January 2007.

The researchers in Golm now plan to use a different function of the muscle-like plant cells, one that could be useful for the construction of aircraft or bicycles. Working in conjunction with the Institute of Textile Technology and Process Engineering in Denkendorf, near Stuttgart, and the University of Freiburg, the Max Planck scientists are developing a new fiber composite material, which they hope will be tougher and stronger than existing materials of this kind. Fiber composite materials already have much in common with the principles found in their vegetable origins: rigid glass, carbon or ceramic fibers are embedded in a soft synthetic material. The fibers give the material its stability, while the synthetic material makes it moldable. The result is a lighter material that is simultaneously more capable of withstanding stresses. The new Boeing 787 is one example of a system built from a carbon composite material of this kind.

**Resilient Tangle of Vegetation**

However, its light weight also entails a disadvantage: the fiber composite materials start to vibrate easily. Vibration does more than just create noise. “It is lethal for a material,” says Markus Milwich, scientist at the Institute for Textile Technology and Process Engineering in Denkendorf. “In aircraft construction, vibrations make a material brittle over time, until it finally breaks,” explains the engineer.

Although wood cells have a structure similar to fiber composite materials, trees put up tough resistance to many storms and do not break just like that. “Plant cells have a trick they use to maintain resilience,” says Ingo Burgert. The hemicellulose fibers in the soft sponge are firmly attached to the stiff strands of cellulose. There are short fibers and long ones, which are embedded in the sponge to different depths. The tangle of hemicellulose fibers therefore becomes increasingly light as it gets further away from the cellulose fibers. This gradually transfers the stiffness of the cellulose fibers into the softness of the surrounding sponge. The stem breaks only if a vast number of the microscopic fibers are torn.

Engineers at the Institute for Textile Technology and Process Engineering have created a model of the natural principle with the help of silicon oxide nanoparticles. They immersed glass fibers in a nanoparticle solution before embedding it in artificial resin. The nanoparticles fastened themselves onto the fibers in a thin layer. “The shell of nanoparticles is softer than the glass fiber, but stiffer than the resin,” says Milwich. Thus, as with plants, there is a transition between stiff and soft.

In testing the material, the scientists made an unexpected discovery: the nanoparticles not only made the glass fiber material stiffer, but also caused the test columns to vibrate less easily. “Now, we would like to try to get even closer to the natural model.” They plan to pack the glass fibers into several shells of nanoparticles with a stiffness that declines toward the surface, so that the fibers eventually merge into the resin. The researchers hope that the material will then be even better at dampening vibrations.

If they succeed, using fiber composite materials in construction could become much cheaper, says Milwich. “In aircraft construction, the vibrations are dampened with additional films,” says the engineer. “If the composite material itself prevents the vibrations, this extra cost could be avoided.”

And so engineers are rediscovering wood. Not just as a material, but as a major source of ideas as well.

**CHRISTIAN MEIER**

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And so engineers are rediscovering wood. Not just as a material, but as a major source of ideas as well.
The Trans-Siberian Railway conjures up images of winter landscapes, solitude and adventure. Since 1995, scientists from the Max Planck Institute for Chemistry have been joining travelers on the train to study the role of Siberian forest fires and methane emissions in climate change. While the scientists may be spared the coldness and solitude, there is always a bit of adventure to be had on the expeditions from Moscow to Vladivostok.
Russia’s vast marshes, taun-dra, boreal forests and per-mafront areas affect the global balance of greenhouse gases. Back in the early 1990s, Nobel Prize winner Paul Crutzen, Emeritus Director at the Max Planck Institute for Chemistry in Mainz, had an idea as to how to remedy this problem of monitoring. He wanted to convert a railroad car into a measuring coach – and couple it to the train affectionately known as the Transsib, which traverses well over three-quarters of Russia. “So Paul Crutzen arranged a collaborative project with his colleague Georg Golistyn from the Russian Academy of Sciences,” explains Carl Brenninkmeijer, head of the project at the Mainz-based Max Planck Institute: “Somewhere, our Russian colleagues managed to get hold of a discarded railroad from Russian Railways and signed numerous agreements with the appropriate au-thorities.” Supported by the Volks-wagen Foundation and Ruhragas AG, the German scientists then sent large numbers of measuring instruments to Moscow to fit out the railroad. “Because there wasn’t much there,” recalls Brenninkmeijer. Even screws, tools and batteries for the railroad’s power supply had to be sent to set the scientific mission in motion.

ENVIRONMENTAL PROTECTION MISSIONS

Since 1996, scientists have been boarding the Transsib’s special railcar almost every year, mostly between April and October. Around a dozen researchers join the expeditions, most of them from Russia. They use the missions as a chance to carry out routine checks on environmental pollution. However, they are frequently accompanied by German scientists, primarily from the Max Planck Institute for Chemistry in Mainz, and sometimes scientists from the USA and the Netherlands, as well. They spend two weeks together on board the train, traveling some 18,600 kilometers from Moscow to Vladivostok and back.

“You quickly get used to the par-ticular rhythm of the trains,” says Eva Oberländer, who spent time on board gathering data for her work as a post doc at the institute in Mainz. The rhythm owes to the Russian climate: the temperature fluctuates so dramati-cally between summer and winter, and the Siberian frost takes such a toll on the rails that the edges cannot be welded, as they are in Germany. To give the metal more room to move, the Russian engineers leave gaps be-tween the rail sections, which creates that special acoustic signature that is so clearly audible to those on board.

But it’s not just the acoustics that distinguish this laboratory from the rest: the work on board never stops. The scientists work in shifts, keeping an eye on the instruments that measure methane, carbon dioxide, nitrogen oxides, ozone and the isotope 222 of the noble gas radon. Radon escapes from the Earth and behaves like the greenhouse gas methane at the interface of different air layers. During an atmospheric inversion, when the upper air layer is warmer than the one below it, radon accumulates at the temperature thresholds in the atmosphere. Scientists know that approximately one molecule of the radioactive gas escapes from the Earth per square centimeter per sec-ond. They can therefore use its actual concentration in the air to deduce how fast it is escaping into the upper layers of the atmosphere. Methane is diluted at a similar rate.

While some researchers keep their eyes on their screens so they can take direct action in case of any dis-turbances, one member of the expe-dition is constantly logging every-thing the train passes on its journey: marshes, grassland, sometimes a burning forest, another train or a vil-lage with smoking chimneys. And, of course, the scientists also collect air samples that they analyze when they return to Mainz. A funnel on the roof of the train channels the air into a manifold located in a look-out dome on the roof. From there, the re-searchers compress the air into alu-minum containers.

SINGLE ROOMS FOR WOMEN ONLY

Space is tight under the glass dome when just two scientists squeeze themselves in – and they can stand up only with heads bowed. Although they don’t have to strain their necks everywhere in the measuring coach, the expedition participants do need to squeeze past each other between the measuring instruments stacked around the walls. “And in the sum-mer, it’s stuffy and over 30 degrees Celsius inside,” says Eva Oberländer.

At least she, as a woman, gets to sleep in a single cabin directly inside the measuring coach. Her male colleagues, on the other hand, have to share cabins. They get a taste of the real Transsib atmo-sphere in the process, spending their rest periods in the couchettes that traverse Russia’s mainline railway network according to schedule. The Transsib is packed with travelers and their baggage most of the time; it still represents one of the most im-portant connections between Rus-sia’s distant east and the more dense-ly populated areas in the west. The scramble begins as soon as they arrive at Moscow’s Yaroslavsky

You can’t fail to hear the differ-ence: the rhythmic “tadum...ta-дум...tadum” of the wheels creates a unique background noise for a labo-ratory. Wherever science is practiced, there tends to be lots of noise – compressors rattling, cooling units buzz-ing and pumps wheezing, as if in competition with each other. But the clattering that accompanies the ex-periments conducted here is the au-dible signature of a special kind of scientific tool: the Trans-Siberian Railway.

The laboratory carried on this train delivers data on the composition of the atmosphere for a project called Troca. The acronym stands for Trans-Siberian Observations into the Chem-istry of the Atmosphere. Here, scien-tists measure concentrations of the typical greenhouse gases methane and carbon dioxide, as well as nitrogen oxides, carbon monoxide and ozone in the air across the different regions all the way from Moscow almost to the Pacific. Their findings ultimately provide pieces of the puzzle to help them understand the chemistry of the atmosphere, the breakdown of atmo-spheric pollutants and Siberia’s role in the Earth’s greenhouse effect.

The denser the network of measur-ing stations, the more scientists can learn about these things. But in Rus-sia, it is simply impossible to weave large gaps in their knowledge of how
station. The Max Planck researchers carefully load their crates of empty sample containers onto the train; things are relatively calm here compared to the run-up to the departure of a German intercity train – those taking this journey are in no rush. Once the guard blows his whistle signaling departure, passengers can lean back in comfort or lay on the spartan sanitary facilities, with a cooking skill the dimensions of the kitchen pose a challenge, if nothing else. But even working in this tiny space, she manages to fill the stomachs of all expedition members. In fact, the participants get used to all of the other inconveniences of this scientific living community on wheels within a few days, as well. Like the spartan sanitary facilities, with a shower that doesn’t offer up warm water until the sun has heated the tank during the daytime – and even then the water quickly runs out. Generally, the team swiftly grows accustomed to everyday life in the measuring coach. The routine makes time pass faster as the Transsib snakes its way across some 2,000 kilometers on the edge of the South Siberian mountains after passing Krasnoyarsk – the city where foreigners were banned until just a few years before the first Troica mission because it was a military no-go zone.

It’s not only a visit to the once-forbidden city that turns the Troica expeditions into a series of exciting journeys for Eva Oberländer. She is of Russian-German descent and her first Troica mission, Troica 5, took her to Siberia for the first time. “I find the landscape very impressive,” says the scientist, who now works for a Swiss medical technology firm. She is especially fascinated by Lake Baikal, along whose shoreline the train winds its way for more than 200 kilometers. The Transsib approaches the lake and the city of Irkutsk on its shores through the boreal forests, or taiga, adorning the northern fringes of the South Siberian mountains.

4,000 KILOMETERS OF WOODLANDS

Larches are the main flora here, whose needles change to a warm, yet somber shade of ochre in the fall. Occasionally, the tree cover encroaches and calm rivers or still lakes appear like mirrors beside the railroad line. And there are only infrequent glimpses of concrete-block settlements and villages – to call them functional would be a compliment – that seem to have shoe-horned their way into gaps between the forests.

The scenery of the taiga’s coniferous forests accompanies the Transsib for

FASCINATING RESEARCH

station. The Max Planck researchers carefully load their crates of empty sample containers onto the train; things are relatively calm here compared to the run-up to the departure of a German intercity train – those taking this journey are in no rush. Once the guard blows his whistle signaling departure, passengers can lean back in comfort or lay on the train’s bunks. Most of the scientists, however, can forget about relaxation once the train has left the station.

During that time, the German scientists have to wait almost 2,000 kilometers – about two days’ journey time – before they reach one of the research regions where the atmospheric chemistry is particularly interesting: the West Siberian marshes. Before that, the train passes through large stretches of methane bubble up out of the soil here. One of the questions the scientists are trying to answer is whether it comes from natural gas deposits or from bacteria living in the marshes. The answer will be revealed by the isotope studies to which they will subject their air samples when they return to Mainz. This will allow them to find out how much carbon with atomic mass 12 the methane contains, and how much carbon with atomic mass 13. Bacterial enzymes cannot process molecules containing the heavier carbon as well – in other words, the methane they produce contains less carbon-13 than methane from natural gas deposits.

MORE METHANE THROUGH CLIMATE CHANGE?

“We can use the knowledge obtained from the Troica missions over the years to help understand the link between the natural methane emissions from these wetlands and climate change,” says Carl Brenninkmeijer. Higher temperatures are gradually melting the permafrost, which, at least in northern Siberia, stores a lot of methane. If that gets into the air, too, climate change will intensify even further.

The Transsib reels off the kilometers through the West Siberian wetlands for more than a day. The track between Omsk and Novosibirsk is almost dead straight. By day, you can see all the way to the horizon in the distance, and the dark of night is periodically broken with flashes of blazing orange from the fires burning above the gas fields. The researchers must log every one of them in their logbook so that they can determine what caused any potential deviations in their measurement curves.

Somewhere along the line, the generator malfunctions, but the Russian scientists quickly fix it with a coin. “That’s where their talent for improvisation comes in very handy,” says Carl Brenninkmeijer. And so the scientists have yet another anecdote to retell over dinner. Communal meal times are mostly high-spirited affairs, although everyone observes the dry law, as the ban on alcohol is called here. The limited space doesn’t spoil the atmosphere, even though there’s no room for a table. They eat sitting at their desks or standing in the measuring room. Some discuss the measurement results displayed on the walls in the corridor by the sleeping quarters. The team has a dedicated cook, for whose cooking skills the dimensions of the kitchen pose a challenge, if nothing else.

But even working in this tiny space, she manages to fill the stomachs of all expedition members. In fact, the participants get used to all of the other inconveniences of this scientific living community on wheels within a few days, as well. Like the spartan sanitary facilities, with a shower that doesn’t offer up warm water until the sun has heated the tank during the daytime – and even then the water quickly runs out. Generally, the team swiftly grows accustomed to everyday life in the measuring coach. The routine makes time pass faster as the Transsib snakes its way across some 2,000 kilometers on the edge of the South Siberian mountains after passing Krasnoyarsk – the city where foreigners were banned until just a few years before the first Troica mission because it was a military no-go zone.

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The scenery of the taiga’s coniferous forests accompanies the Transsib for
some 4,000 kilometers – until it passes Chita and Khabarovsk near the Chinese border, where the faces of the local population show strong Mongolian features. 

Between April and August there are frequent fires in the forests that line almost half of the expedition’s length. These woodlands make up one-tenth of the world’s woody biomass. A single forest fire near Khabarovsk once released 60 million tons of carbon dioxide into the air. “The fires show themselves as pronounced peaks in our measurements,” says Brenninkmeijer. The instruments react to much lower concentrations. They are even sensitive enough to register the carbon monoxide coming from the samovar. But unlike the samovar, the forest fires have a significant effect on the amount of carbon dioxide in the northern hemisphere. Exactly how significant is something the atmospheric researchers still need to find out.

During the first seven Troica missions – this summer the Max Planck scientists’ Russian partners completed their eleventh – the traveling researchers could allow themselves and their instruments a one-day break after the Transsib had left Khabarovsk. That was because, up until 2002, the train was pulled by a diesel engine for the rest of the journey to Vladivostok. Anything the scientists might have captured in their analyzers and air sample containers would have come chiefly from the locomotive’s chimney. However, these 700 kilometers have since been electrified, allowing the researchers to continue their work all the way to the Pacific.

This puts an end to the scientists’ free day off, but they hardly seem to notice. “Working in shifts keeps the adrenaline pumping,” says Eva Oberländer. And the time difference does its bit as well. In Vladivostok, it is seven hours later on board than it was back in Moscow. But there’s little time for a leisurely stroll through the streets, as the train embarks on the return journey in just a few hours’ time.

Weather Shapes Atmospheric Chemistry

The expedition members go on busily collecting data throughout the return journey. A change of weather gives them insight into the influence of sun, wind and rain on the chemistry of the atmosphere. For the Max Planck scientists and some Russian guests, however, the real work first begins when they get back to Mainz. That is when they start analyzing their data and the 70 or so air samples they have shipped back to Germany, sometimes involving considerable red tape. “We’ve had quite a few misunderstandings to clear up with Russian customs officials before they would let our sample holders, which are pressurized at about 6 bar, leave the country,” says Eva Oberländer. The data shows that the West Siberian wetlands release large quantities of methane – which the scientists expected. But where does it come from? By analyzing the isotope ratio in the methane, the chemists from Mainz discovered that the surplus of methane over the West Siberian wetlands originates almost entirely from bacteria in the ground. Only one of the mighty gas pipelines that the measuring coach crosses near Perm, back in Europe, leaves a distinct industrial trace in the isotope profile, although the scientists also detect a leak at one of the gas fields near Novosibirsk in their data.

Whereas methane bubbles up from the ground where it is waterlogged, carbon dioxide is chiefly produced when grassland or woodland burns – areas like the taiga lining the 3,000 kilometers between Lake Baikal and Khabarovsk. The scientists are keen to study how these carbon dioxide emissions vary depending on the season.

Trousting the Power of Improvisation

They also want to find out how much stronger climate change is becoming in western Siberia as a result of the methane released from the permafrost there. However, more expeditions will be needed to do that. “Perhaps only two a year, one in summer and one in winter, even though the conditions are very difficult then,” says Brenninkmeijer: “We are trying to get the expeditions financed by the Russians.” In official circles, however, there is a certain reluctance among Russian politicians when it comes to meeting requests from overseas. But perhaps Russia’s scientists will find a way to continue the cooperation without official support. Carl Brenninkmeijer, for his part, is optimistic: after all, he is familiar with the Russian scientists’ resourcefulness and talent for improvisation.

Not a stunning view – through the lookout, the researchers note what lies on both sides of the track. Marshes, forest fires and pipelines can be pinpointed in their measurement data.
Unicellular Whispers

Occasionally, they can be seen with the naked eye: small orange-yellow spherical structures. Closer examination reveals that they are accumulations of countless bacteria of the genus Myxococcus. The ability to form these fruiting bodies when food supplies are short requires a sophisticated system for intercellular communication that allows hundreds of thousands of single cells to interact in a coordinated fashion. LOTTE SOGAARD-ANDERSEN and her team at the MAX PLANCK INSTITUTE FOR TERRESTRIAL MICROBIOLOGY in Marburg are on the hunt for the molecular basis of this complex social behavior.

Bacteria are unicellular organisms and tend to lead a relatively simple life. As independent individuals, they follow their own agenda, and intercellular communication is of no great importance to them – at least, that was previously the view. In recent years, however, it has been necessary to revise this perception. Bacteria do indeed communicate with each other, both within their own species and between species. In this process, they exchange signal molecules, not words, in a form of chemical communication. Numerous processes typical of bacteria, such as infecting humans, animals and plants or stimulating plant growth, crucially depend on their ability to communicate.

My research group at the Max Planck Institute for Terrestrial Microbiology in Marburg uses the unique intercellular signaling system in Myxococcus xanthus to investigate how bacteria communicate with each other. Among the myxobacteria, M. xanthus is the ideal model organism to investigate in the laboratory. Its genome was completely sequenced recently, which allows us to carry out detailed functional genome analysis, and we can also in-
starvation situation is genuinely sensed for a large population of cells.

The C-signal takes action only if the cells have passed this checkpoint successfully. It coordinates three different processes: First, it triggers the aggregation of cells into the fruiting bodies; we will see later how that happens. In the late phase of fruiting body formation, the C-signal induces the sporulation process – that is, the conversion of the cells that have accumulated in the interior of the fruiting body into robust spores. At the body formation, the C-signal induces different processes: First, it triggers the aggregation of cells into the fruiting body and then anchored in the outer robust spores. At the same time, the C-signal switches on a set of developmental genes.

**Signal Transmission Only on Physical Contact**

In order to understand how a signal coordinates three different processes that take place at different times and in different places, we have concentrated on explaining the pathway of the signal. What happens here exactly? First, the C-signal must be produced. As already noted, bacteria converse using molecules, not words. The synthesis of the C-signal molecule depends on the csgA gene. It is interesting that the protein exists in two forms: a long version, which has a mass of 25 kilodaltons and is therefore referred to as p25, and a shorter variant of only 17 kilodaltons, known as p17. We were able to show that p17 is the C-signal. It is made from p25 by proteolytic cleavage and then anchored in the outer membrane of the bacterial cell. The C-signal is thus a non-diffusible protein located on the cell surface.

This is surprising, since most of the intercellular signals discovered in bacteria are small, diffusible molecules with a mass of less than 1,000 daltons. As a rule, they are part of a quorum sensing system that helps the bacteria estimate the size of their population: when the number of cells is high enough to trigger an efficient infection.

Why does *M. xanthus* use a cell-surface-associated signal molecule instead of a freely diffusible molecule? The answer is probably that the bacterium is simply too slow. The cells can only move at an average speed of two to five micrometers per minute (that would be the equivalent of a maximum of seven millimeters per day). This speed is so slow that the directional signals of a diffusible signal would have disappeared before the cells could orient themselves according to the concentration gradients – that is, the different concentrations of the signal in different locations. In order to circumvent this problem, *M. xanthus* has acquired a signal molecule that cannot help but move at the same speed as the cell because it is anchored in the cell membrane. It permits the cell to orient itself without losing its sense of direction.

However, to allow the C-signal to be transmitted, two cells must come into direct contact with each other. It has not yet been possible to identify the C-signal receptor on the receiving cell. The first component on the receiving side that we know about is a DNA binding protein called FruA. The A-signal mentioned above induces the synthesis of this protein when the gene is transcribed, and the C-signal presumably triggers its phosphorylation (by attaching a phosphate group). At least, that is what we suspect, although we have not yet identified the relevant enzyme (a kinase). Phosphorylation is a widely used mechanism for activating proteins.

At this point, the signal system branches out. It can take two different routes: one route leads to aggregation, whereby a protein is modified that, combined with other proteins, regulates the behavior of the bacteria cell, or more precisely, controls the frequency with which it turns. Normally, *M. xanthus* cells change the direction in which they are moving. However, in cells in which the C-signal is switched on, the frequency with which the cells change direction decreases and these cells move directly to the aggregation center. The second branch leads to sporulation. The C-signal and FruA jointly regulate around 50 different genes.

**Exciting Conversations with Neighboring Cells**

During fruiting body formation, aggregation always precedes sporulation. The cells do not stop sporulation until the aggregation process has been completed. Moreover, in order for cells to sporulate, they must be located inside a fruiting body. As the C-signal controls the aggregation and the sporulation, the question arises how it can control these two processes in time and space. The mechanism functions comparatively easily. We were able to show that aggregation and sporulation are triggered at different threshold values. The C-signal is amplified via two control circuits. As the density of cells increases, more and more neighboring cells come into contact with each other and transmit their C-signal. This results in increased transcription of csgA in the cells, and thus in an increase in the C-signal. The cells can now transmit the C-signal at a higher level to their neighbors. All the cells involved in the transmission of the C-signal are thus exposed to ever-increasing C-signal activity, which, at a moderate level, triggers first the aggregation, and at a higher level, sporulation.

This mechanism ensures that the C-signal reflects the cell density and thus also the position of the individual cells. Only the cells in the interior of the fruiting body have sufficient contact with neighboring cells to reach the high signal activity that finally causes conversion to spores. Using the C-signal, a cell can decode its position relative to the other cells and adjust the gene expression and sporulation according to its position.

In order to understand the whole of the C-signal pathway, we are now trying to identify the other components in the pathway. These include the proteases, which cut the p25 protein down to the actual C-signal molecule, p17, the C-signal receptor, and the kinase that phosphorylates the FruA protein.
One of the giant tortoises may still be able to recall the young Irenäus Eibl-Eibesfeldt making landfall on the Galapagos Islands 50 years ago. It was the second time the behavioral scientist had visited the Pacific archipelago: 1,000 kilometers off the coast of Ecuador. This time he was there on behalf of UNESCO, and he came up with a concept to save this paradise on Earth, a place that had already impressed Charles Darwin and inspired him to write his Theory of Evolution.

Charles Darwin's visit to the 14,000 goats are now being hunted, and helicopraters are another problem. They are constantly moving to Galapagos to live. Restrictions need to be implemented. Since 1959, all of the area of the Galapagos Islands that was to look for Galapagos tortoises. This island, with its humid climate and fertile soil, is inhabited – mostly by Ecuadorians, but there are a few Europeans there, too. They cleared ground to establish banana and coffee plantations, among other things. And they slaughtered tortoises for their tasty meat. Eibl-Eibesfeldt's group saw entire fields of tortoise carcasses – in spite of the laws passed in Ecuador back in 1934 protecting creatures like tortoises, land iguanas, marine iguanas, penguins, sea lions and fur seals. But that wasn’t the worst of it. On the tiny Las Plazas islands to the east of Santa Cruz, which ought to be an idyllic rich in animal life, one of Eibl-Eibesfeldt's walks on the beach brought him upon the seemingly consuming corpses of six sea lions with their skulls smashed in. The animals had obviously been butchered by fishermen who felt they disturbed their fishing. And on the small island of Baltra north of Santa Cruz, a refuge for Galapagos land iguanas, the scientist found a single example of the species. It was already, as indicated as much in an interview this year: "Tourism is going to become a problem," he predicted, "because the ships are getting bigger and bigger. In these days, around 100,000 visitors are passing through the islands at (at the moment about 30,000 live there), its all over." The behavioral scientist cited the domestic goats that are allowed to run wild as another problem. They are constantly encroaching into new areas, eating all the vegetation there and destroying the basis of life for the tortoises and other land animals that have since occupied some action: the 14,000 goats are now being hunted, and helicopters are even being used to shoot them down. Irenäus Eibl-Eibesfeldt got to know the Galapagos Islands on his many research trips and has followed events there over five decades. His first trip to the archipelago was thanks to marine scientist and underwater cameraman Hans Hass, who invited the biologist, then 25, to join him on a 12-month expedition to the Caribbean and the Galapagos Islands on his three-masted schooner Xarife in 1953/54. Hass's goal for the expedition was to develop his new method of free-swimming diving and filming for scientific use. He no
The discovery of insect pheromones revolutionized the battle against harmful insects – a highlight of chemical ecology. At the 23rd Annual Meeting of the International Society of Chemical Ecology (ISCE) held in Jena in July and co-organized by the Max Planck Institute of Chemical Ecology, some 300 scientists from 30 countries discussed the latest findings on the complex relationships between plants, animals and microbes.

Relaxing in a summer meadow, listening to the buzz of bees, watching a caterpillar leisurely inch its way up a stalk, aphids obligingly milk them – a peaceful scene on a gentle slope above Jena in the German state of Thuringia. But what an illusion! These are dramas playing out in meadows, forests and hedges – dramas of death and downfall, hunting and enticement, attack and defense. Just because humans lack the appropriate senses, we fail to notice the daily fight for survival that continuously goes on between plants and their adversaries: insects, fungi, bacteria and viruses.

Alluring calls, warning calls, calls for help – we rarely perceive them because they are not acoustically or optically encoded. We know them only as the seductive fragrance of a spray of flowers, or as the heavy bouquet of a freshly mown field. Fragrant chemicals, emitted in extremely low concentrations, are what plants use to communicate. If we could see them, a meadow or a section of forest would be awash in trails of molecules and softly billowing clouds of fragrance. If we could hear them, the screams of battle would destroy any summer idyll. But people have no natural sense or comprehension of the molecular language of plants.

Down below, in the city on the Saale, a group of scientists gathered who do understand this language, who decode it, molecule for molecule. In their research life, chemical ecologists collect substances like taxonomists collect beetles in their boxes. Every new substance that they successfully decode and synthesize is one more letter in the alphabet of chemical communication. They presented and discussed their latest findings with their colleagues at the Annual Meeting of the International Society of Chemical Ecology (ISCE). It was no coincidence that the 23rd meeting was held in Jena, the city of Ernst Haeckel, the “German Darwin,” who introduced the term ecology. “The Max Planck Institute of Chemical Ecology is celebrating its 10-year anniversary this year,” says conference organizer Wilhelm Boland, Director of the Department of Bioorganic Chemistry at the institute in Jena.

Furthermore, Jena is even considered one of the birthplaces of chemical ecology and of the study of the defense chemistry of plants: this was where, 120 years ago, Ernst Stahl investigated how plants react to slug damage. However, as has so often happened in the history of science, his approach was lost. It wasn’t until the 1950s and 1960s that insect researchers turned the attention of chemists to plants’ reactions to insect attacks. Since then, they have deciphered large portions of the communication puzzle. “For example, we have learned that secondary metabolic products that the plant or its nematodes or animals that disperse the seeds. But they also make up a large part of the plants’ defense forces, either as messenger substances, like the plant hormones jasmonic acid and salicylic acid, or as defense substances, like the mustard oil glycosides, the terpenes or the tannins. It takes some time before a plant activates its defenses: genes for their production are adjusted up and down, enzymes are produced, and defensive compounds are synthesized. Scientists now have a very good understanding of all of this. It was only what happened in the first seconds to minutes when a caterpillar takes its first bite from a leaf that long remained in the dark. Massimo Maffei from the University of Turin and Wilhelm Boland have shed light on this early time period. Their first key discovery: the feeding attack of a caterpillar changes the electrical potential of the affected cells and their neighbors in such a way that the resulting depolarization wave propagates alarmingly, within just minutes, across the entire leaf. “Now we have to find the connection with the subsequent signal cascades,” says Maffei.

To undertake controlled studies of these and other reactions of the plants to attacks by herbivores, Boland and his colleagues are counting on a mechanical assistant – Mec-Worm, a kind of stamping robot.
CONGRESS


Meetings among the posters offered many occasions for animated discussions.

As is typical for a symbiosis, both the fungus and the bacterium benefit from the fatal alliance because they draw nutrients from the dying rice plant. The fungus is so dependent on the bacterium that it can no longer even breed without it. “When we remove the bacterium, the fungus no longer produces spores,” says Hertweck. However, it still remains to be seen whether this means that rice seedling blight can now be controlled better: “We can’t spray the fields with antibiotics against the bacterium.”

But since the scientists already know what the true toxin factory is, the bacterium, it may be possible to use this knowledge to develop more effective variants of rifaxin as a tumor toxin, because it has been known for some time that rifaxin also prevents cell division in cancer tumors, and has repeatedly sparked the interest of cancer researchers. However, there has not yet been any resounding success. That could be a new highlight in chemical ecology.

Maxim Anasov
“Plants were mostly underestimated”

Researchers have known for years that, in plants, attacks by chewing insects trigger defense reactions that are communicated within the organism by chemical signal cascades. However, early events triggered in the plant by such an attack long remained in the dark. Massimo Maffei from the University of Turin and Wilhelm Boland from the Max Planck Institute of Chemical Ecology in Jena are pioneers in the study of these initial moments of insect-plant interaction. MaxPlanckResearch interviewed the two scientists at the Annual Meeting of the International Society of Chemical Ecology.

MaxPlanckResearch: Scientists now understand quite well what occurs in a plant when an insect attacks. Only right at the beginning, in the first seconds and minutes, was it long uncertain what happens. Why was that previously overlooked?

Wilhelm Boland: No one was working on these questions. Until five or six years ago, everyone was focused on plant hormones, which are produced only much later in the attack – how they interact with other substances and how they control the defense. And of course a key focus was measuring secondary metabolites, about which it was previously thought that they had no function whatsoever. Today, we know how important they are for the defense of the plant. This was studied with established biology and chemistry methods, such as microarrays and other molecular biology techniques. Anyone can work with these. However, in the case of the “early events,” in other words the reactions of the plant in the first seconds up to about 20 or 30 minutes into an insect attack, the situation is completely different. This requires a great understanding of chemistry and physics, especially of electrochemical methods – but there are only a very few specialized labs in the world that can conduct these studies – including ours here in Jena and the one in Turin.

MPR: So what happens in this early phase when, for example, a caterpillar tears its first pieces from a leaf?

Massimo Maffei: There are various substances that act in different time periods, and each substance has its own timing. First, there is the interaction of the insect with the cell membrane, which upsets the balance of the ions located on both sides of the membrane. A membrane uses ion pumps to actively maintain a difference between the ions on the inside of a cell and those on the outside. One side is more negatively charged than the other – we call this the membrane potential. This difference between the outside and the inside must remain constant because it constitutes the balance of the living cell. Influences from outside can shift this balance completely destroy it. Those are the first early signals with which the cell perceives that something is happening outside.

Boland: And it is the first effect that we can measure with our methods: when a tissue is destroyed, depolarization of the membrane occurs in the first seconds.

Maffei: Precisely. But initially only at the location of the bite. The depolarization is so strong that it triggers action potentials in the cells. An electrical wave then propagates outward from the bite site across the entire leaf at a speed of about one centimeter per minute. Seconds after depolarization, massive quantities of calcium ions flow into the cell. A little bit later, hydrogen peroxide production is increased, which is a known reaction when plants are attacked by herbivores. Only some 10 to 20 minutes later do we register a change in the concentration of such plant hormones as jasmonic and salicylic acid. And after about an hour, we see the first changes in gene regulation and the concentration of secondary metabolites that are then used as defense compounds.

MPR: What role do substances such as calcium play in an insect attack?

Maffei: These substances are involved in signal transduction. This is comparable with what is happening here in our interview: there is a kind of microphone that receives the signal, and something that then amplifies it. Here, we have the receptor that takes care of amplification. In plants, it is the cell. Something is needed to boost the signal and then transmit it. Calcium is involved in transmitting the signal.

MPR: So what is the connection between these early events and the later signal cascade that ultimately leads to the defense reaction?

Boland: That is one of the key questions to which we don’t yet have an answer. There are assumptions, especially regarding the role of the calcium, but no final proof. However, we know that many of the enzymes that are related to the production of plant hormones, such as phospholipases, are activated by calcium ions. This means that, when the reverse influx of calcium ions in the cell, this could activate the phospholipases – and ultimately the entire cascade, right down to the phytohormone jasmonic acid. This has not yet been shown, but it is a logical sequence that makes sense. To put it simply, the key question is: How does an electrical wave become a meaningful physiological signal?

MPR: Are their electrophysiological measurements comparable with those from animal cells?

Boland: From a technical standpoint, there is no difference. In plants, however, the cell wall makes the task much more difficult. The goal is the same, too: we want to measure the charge distribution on both sides of the cell membrane. When positive ions, such as calcium, flow in from the extracellular space, a hyperpolarization occurs; when they flow out in large numbers, a hyperpolarization occurs. Accordingly, negative ions, such as chloride, cause the opposite reaction. In plants and animals, the membrane potential is actively maintained, but in different ways. It is very difficult to say how far the similarities go. We shouldn’t overtax the comparison. After all, plant and animal evolution have been separate for a couple hundred million years now.

MPR: But there are researchers who believe that the differences in signal processing and perception between animals and plants aren’t nearly as great as we always think. After all, the term plant neurobiology has since spread through all the newspapers. What do you think of that?

Boland: As is so often the case, the truth is somewhere in between. The term plant neurobiology accomplished exactly what it was intended to: bringing people’s attention to a special kind of interaction between plants and their environment. Quite simply, the term includes the entire processing system, from signal perception to reaction. It was this analogy that led those involved to call it “plant neurobiology”. It was good that they chose this term – it fulfilled its purpose of gaining attention. But now, three or four years later, we should create and use a more precise term.

MPR: And what might that be?

Boland: That’s the problem! We can only describe what it means in a couple of sentences. That is also what makes the term “plant neurobiology” so appealing. Everyone knows what is meant. What we mean is nothing other than a very comprehensive description of “picking up a signal, processing the signal, and responding to the signal.”

Maffei: Interestingly enough, the same debate took place over plant physiology at the turn of the 19th century. Then, too, people claimed: there is no such thing as a physiology of plants, that it applies only to animals. But plant physiology is now a completely established field.

Boland: The debate arose over plant hormones, too. Today, we call them phytohormones. And no one gets upset about it anymore.

MPR: But aren’t some proponents taking it a bit too far when they use such terms as intelligence or brain in connection with plants?

Boland: In my view, they do this to dispel the preconception that only humans and animals are capable of interpreting signals and stimuli and reacting to them, while plants are inactive and stupid. And one method of breaking down preconceptions is by choosing specific words: speaking, for instance, of a kind of self-awareness in plants because the roots can distinguish themselves from those of another plant. Of course this is not the same as human self-awareness, but the cells do recognize: those are roots of another plant, not their own.

Boland: It is also a means of showing that plants were largely underestimated. A plant can be viewed as a complex processing system, just like an animal, with many sensors and many response elements. The plant always notices what is happening in the distant roots or in the leaves. When one part is destroyed, this is somehow perceived, and that part then interacts with the other parts. For example, damage to the roots can cause the leaves to emit fragrances that are then noticed by parasites or whoever. The plant lives in a vast interactive sphere, both above and below the Earth, filled with chemical compounds that supply countless tidbits of information. It is exposed to numerous interactions, and that is why it must also be constantly aware of what is going on around it.

INTERVIEW: Markus Ahlásze

PHOTO: NORBERT MICHALKE

MAXPLANCK INSTITUTE OF CHEMICAL ECOLOGY

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The Tough Road to Sobriety

Alcohol is offensive and dirty. Alcohol shows its dark side in the homeless man crawling into his sleeping bag under the bridge, in the guy searching through garbage cans for leftover food. The dark side of alcohol is nasty. Hannelore Ehrenreich learned that in the emergency room of the Medizinische Poliklinik, München (Medical University Hospital, Munich). Hardly a night goes by without some drunk with unspecified pain, epileptic attacks and lacerations being admitted into her care. Desolate people who’ve fallen over in a stupor. Some of them she sees over and over again. They are hardly out the door before they end up back at the hospital, dead drunk again.

Many of Ehrenreich’s fellow doctors are disgusted by the disheveled patients and want to get rid of them as quickly as possible. Some doctors give the troublesome drunkards another drink – to calm them down when they get too worked up. They suture their wounds. But no one wants to know about alcoholism, and especially – if the alcoholic turns up in a nice pinstripe suit. Ehrenreich experiences firsthand that the widespread disease of alcoholism does not stop at social boundaries. She is shocked by her colleagues’ ignorance and their verdict that “It’s their own fault.”

The consultant in psychiatry and neurology asks herself if it really is only the patients’ own fault they are sick. Alcoholics are short-tempered and irritable. She sees that every day. She is convinced that the balance of stress hormones in the affected individuals is disturbed. There have been no systematic studies of that so far. Hannelore Ehrenreich decided to make up for it, going against those who say you should leave well alone. For many of her patients relapse within the first year. OLITA is assumed to work so well because it is not like conventional therapies, and dispenses with therapeutic dogmas. And also because it has some unusual beginnings.

When Hannelore Ehrenreich decided in 1993 to conduct her stress study, her colleagues smirked and said “You’ll never manage.” At the time, having just returned from a research residency in the USA, she was working in the psychiatry and neurology clinics of Georg August University in Göttingen. She was well aware of the limits of detoxification and therapy – without success. All in all, the prospects are bleak. But OLITA works. More than half of the patients remain abstinent through the years. Other therapies have much lower success rates. Even the most established methods see more than two-thirds of patients relapse within the first year. OLITA is assumed to work so well because it is not like conventional therapies, and dispenses with therapeutic dogmas. And also because it has some unusual beginnings.

“Spurred on by colleagues’ criticism through the OLITA program in almost 10 years. Ehrenreich shows pictures of the ones who were willing to be photographed: portraits of women and men with tired, glassy eyes and bloated, strangely aged faces. Her patients have an average age of 44 at the start of the therapy. Top academics – still working – are just as common among them as illiterates and homeless people. More than 80 percent of them suffer from serious, coexisting psychiatric diseases such as depression and personality disorders. Some 13 percent were diagnosed with grave conditions resulting from alcohol addiction, such as liver cirrhosis.

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When Hannelore Ehrenreich decided in 1993 to conduct her stress study, her colleagues smirked and said “You’ll never manage.” At the time, having just returned from a research residency in the USA, she was working in the psychiatry and neurology clinics of Georg August University and at the Max Planck Institute of Experimental Medicine in Göttingen. She was well aware of the limited prospects of success, since her study required the most heavily addicted patients, who are expected to quit alcohol and stay off it for good. Over several months, the researcher took blood samples from them regularly and measured their stress hormones. They can hardly be expected to get through it without a drop of alcohol.

“My colleagues’ criticism was like a red rag to a bull,” says Ehrenreich today. “I wanted to show them I could do it.” But there was a major obstacle for her to overcome: while the clinic’s emergency room was full of potential patients, alcoholics who decided to detoxify were discharged after just three weeks due to the lack of any
heartbeat and vomiting are the consequences. Sometimes the patients’ circulation collapses. That shocks them. But that is how detergent medication works as a protective shield against drinking.

Tabou number two is broken by Ehrenreich’s “aggressive aftercare.” She chases down her patients – until then a no-no. According to the traditional doctrine, the patient must come to the doctor: “But very few of the alcoholics manage that, only the healthy fit ones. Our chronic addicts usually don’t have the strength,” says Ehrenreich. If they don’t turn up for an appointment, she wants to know why. She calls them or visits them at home, asks their friends, neighbors or relatives. That’s the only way the study will be a success, thought Ehrenreich.

And it was a success. Ehrenreich started with 11 chronic alcoholics in 1993. All of them stayed off the drink for months. Furthermore, the study proved that the balance of stress hormones in alcoholics has indeed gone haywire. Even months after detoxification, adrenaline levels in the blood are still much higher than in healthy people. Even minor stimulating blocks result in stress. Reaching for the bottle is all too easy – one reason why alcoholics find it so hard to stay on the wagon. It dawns on Ehrenreich that she has achieved something amazing.

And then she had her big idea. In 1995 she turned the abstinence program into a therapeutic concept – called OLITA. She divided OLITA into several treatment phases – starting with intensive, daily treatment during theadaptive phase, then letting the patients gradually off the leash after several months; meetings only three times a week, then twice, followed, after a year, by group therapy.

Spurred on by its success, OLITA steamed on, full speed ahead. The number of patients rose. During the year 2000, two new OLITA centers were established and the number of patients doubled. Since then, Ehrenreich has even opened a third center, basically a new department, dealing with public authorities, debt counseling. “With the therapists’ support, the patients exercise abstinence in various stressful situations until they reach such a state of stability that they can cope with most of the challenges in their lives without needing a drink,” says Henning Krampe.

It is this long-term abstinence that makes OLITA so remarkable. The research project came to an end in 2005. More than half of the patients are still abstinent today – and many of them have been so for more than ten years. The fascinating thing about it is that patients had a relapse only in the first three years after the start of therapy. After that, no one did. “Despite OLITA’s daily abstinence training, the patients learned about a range of situations in which they were at risk of relapsing. That is quite clearly essential for long-term abstinence,” emphasizes Krampe.

Interest in OLITA, but no money

The concept encountered a huge amount of initial hostility for being too revolutionary. Critics put the fact that no one relapsed once they had passed the three-year mark down to apparent errors in the statistics. Today, however, OLITA has an outstanding image in professional circles. But its future is still uncertain. For Hannelore Ehrenreich and Henning Krampe, their work is done. “We are practitioners of basic research,” they both say. “Our job is to develop the treatment concept, not provide the large-scale treatment. That has to be...
It’s not that the program is too expensive – it just is no doubt that Ehrenreich has their sympathies. But even presented the concept to politicians in Berlin. There have spent the past three years in countless talks with health insurance administrators and many others. They have even presented the concept to politicians in Berlin. There is no doubt that Ehrenreich has their sympathies. But the fact remains that nobody wants to pay for OLITA.

No break in the chain of treatment

It’s not that the program is too expensive – it just doesn’t fit into the healthcare landscape. In Germany, intensive addiction therapies are still an inpatient affair, involving hospitalization. Long-term, inpatient therapy for alcoholics is practically non-existent. Health insurers will pay for no more than one outpatient appointment with an addiction therapist per week. As OLITA has shown, that is simply not enough.

“What’s more, long-term, inpatient therapy almost always takes place in the artificial, protected environment of the addiction clinics.”

Patients are hospitalized for several months. Then they return to their same old world. This is often a shock for them and frequently leads straight to the next relapse. That’s because the patients receive no support in their everyday lives. The success rate of inpatient therapies is estimated to be 30 percent in the first year after the end of the therapy, says Ehrenreich. “But there is a complete lack of scientifically founded statistics,” she adds.

“The fact that such a useful long-term outpatient therapy as OLITA is so difficult to put into practice is ultimately due to the disconnected system of healthcare provision we have here,” says Heinrich Kunze. Until his retirement early this year, Kunze was Medical Director of the Merxhausen Hospital for Psychiatry and Psychotherapy in Bad Emstal and Kassel. He has known about OLITA since the first publications appeared in the 1990s, but he was never able to apply the therapy because it is impossible to get the costs reimbursed.

Whatever serious illnesses patients suffer from, they will always pass through different departments within the healthcare system: A patient with a damaged hip goes to a local orthopedist first. Then they receive treatment in a hospital, followed by rehabilitation in a specialist clinic and subsequent outpatient treatment with a physiotherapist. “All of these areas are separate cost centers. They each try to keep their own costs as low as possible,” says Kunze, “even if that means higher costs somehow else down the line.”

Separating things like that makes no sense for OLITA. A break in the treatment chain would be disastrous. The therapists remain responsible for the patients all the way from detoxification to the conclusion of therapy. In the disconnected system, it is not clear who should pay the costs. The concept of integrated provision represents one way out of the dilemmas, says Kunze. “It is a new form of financing medical treatment from a single budget, enshrined in law since 2004: for certain illnesses, hospitals and clinics, or even local doctors, negotiate a total package. Under the system, the patient remains in the care of one institution – such as a clinic, which cooperates with a neighboring rehab center and with independent physiotherapists – for the entire duration of the healing process. The clinic agrees on the budget with the health insurer and thereby assumes overall responsibility for the patient.

The integrated model already works very well for hip operations, says Kunze. So well that the insurers are even managing to attract new customers. “But alcoholism just can’t shake off its old problem: the negative image. What insurance provider wants to actively market top-notch alcohol therapy to its customers? Private health insurers even completely exclude treatment for addiction.” Nevertheless, Heinrich Kunze remains convinced that the issue of financing OLITA will be accepted in the foreseeable future. He’s just not sure how much longer it will take.

Newspapers and TV stations have carried reports on OLITA and time and again over the years. Each after new article, each TV program, they get people contacting the institute in Göttingen. And Henning Krampe still gets loads of e-mails. “Of course our research group is now working on other important subjects,” he says. “But we do recognize that many people pin their hopes on OLITA.” So far, he is only able to put people in touch with therapy centers that pursue similar approaches. OLITA itself remains on ice. But the researchers from Göttingen cannot simply sit back and wait for the day the insurers give it the go-ahead.

Hannelore Ehrenreich is pursuing a different path: she wants to establish OLITA as a franchise therapy concept – first and foremost to ensure that any therapy based on the approach developed by the Göttingen researchers actually copies the concept the way it was intended in the last detail. But also because this way of doing it might open up a means of financing the therapy even if it does not appear on the list of treatments funded by the statutory health insurers.

And so the scientists from Göttingen are working with Swiss franchise advisors Bellone Syncron. The company’s boss, Veronika Bellone, believes strongly in OLITA: “It is a clearly defined, standardized concept that is ideal for franchising.” A franchising company sells the right to use its concept – together with a consistent corporate image – to independent parties. They then operate businesses, such as boutiques and fast food restaurants, at their own risk. This is another aspect in which OLITA would be revolutionary: a standardized therapy concept with success measurement and quality testing has never before been operated on a franchising basis.

Veronika Bellone and an attorney she knows from the Swiss Franchise Association are currently working to get OLITA into a marketable format – on a pro bono basis in addition to their day jobs. “A form of alcohol therapy is different than a fast food chain. The objective is not to make a fast buck, but to help get a very meaningful concept off the ground,” says Veronika Bellone. She and the attorney are currently putting together a marketing and financing concept. After all, it does need competent therapists who will actually copy OLITA 1:1. “But these kinds of specialists often have their own agendas and do not like being told how to do things,” says Bellone. So she will need to market OLITA convincingly – as a service to mark psychiatric and psychological practices or clinics as something special.

Or what will have been the point of it all?

Hannelore Ehrenreich is very hopeful that the concept can be established through the franchising system, initially in Switzerland. “Having spent 10 years working intensively and very successfully to improve therapy for alcoholism, I do wonder what the point of it all will have been if we can’t get it going,” Long-term outpatient therapy seems to be the way to break the misery for many alcoholics – of that she is convinced. That is why she wants to finally get OLITA on its feet: “I just want to be able to tell myself that I’ve really made a difference, done something good.”
Everyone’s brain functions according to the same blueprint – and yet we speak a wide array of languages. How does the human brain cope with this variety? Which linguistic and functional patterns help it to accomplish this? Ina Bornkessel, head of the independent junior research group neurotypology at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, is searching for answers to these questions. The cornerstone for this research was laid in the childhood of the now 28-year-old – at the other end of the world.

A first glance, the young woman who invites me into her office and serves me coffee and water seems like a typical, very likeable 28-year-old: sunglasses in her blond, pinned-back hair, a stylish summer dress, expertly applied make-up, a winning smile and an open nature. Nor does anything change this positive impression during our discussion – but it quickly becomes clear that Ina Bornkessel is a woman of superlatives. She completed her PhD at the University of Potsdam at the age of just 22 – as the youngest doctoral student in the university’s history, and with summa cum laude, the highest possible grade.

A few years later, she hit the ground running with her independent junior research group at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig – as the youngest group head in the Max Planck Society. This brought her recognition and attention, and so it happened that, in 2006, Bornkessel was first included in the magazine BILD DER WISSENSCHAFT’s “Science’s Eleven” – on the occasion of the soccer World Cup and, shortly thereafter, in the ranks of the “100 minds of tomorrow,” a joint campaign of the German government and German industry.

Another unusual thing about the Berlin native is where she spent her childhood: Tasmania. At the age of seven, she and her mother moved to Australia’s largest island, where she quickly learned English. That was an easy task – the language just came naturally to her at school and at play with the other children. “After just six months, I was correcting my mother, and I soon began to refuse to go to my language classes – they simply weren’t any fun,” recalls Ina Bornkessel, laughing.

Tasmania is probably also what laid the foundation for her current research interest. “I practically grew up bilingual – though not from the very beginning,” says the young researcher. Because of this, both languages somehow simply became second nature to her. Nevertheless, she also constantly mused about the differences. “I questioned very early on why some things are expressed so differently in German than they are in English.”

“Tasmania will always be her home, declares Bornkessel wistfully. “I fly there at least once a year, also to visit my mother, of course, who still lives there.” But also because she can’t stand being entirely without Tasmania. Once, she was flying back to Germany from New Zealand and didn’t have time for a stopover. “That was a very strange feeling. That will never happen again.”

**Home at the Other End of the World**

Nevertheless, when she finished school – she was just 17 – she decided to go to Germany to study. Her childhood memories had faded somewhat and she wanted to know what it was like to live here. “No one here can really imagine it,” says the scientist, “but just like young Europeans dream of going down under, many Australians want to go to Europe – to travel or even to study and work.” The history, universities with a centuries-old tradition, the many different cultures that exist here side by side and yet still retain their own characteristics – that’s just fascinating for people from the red continent. And yes, here, again, it was, of course, the languages that attracted Bornkessel. “It’s fascinating how so many different languages exist here in such a small area,” she says with an excited gleam in her eyes. “You drive a few kilometers, cross a border that you hardly notice, and suddenly the people speak an entirely different language.”

So the passion for languages, and especially for how they work, how they are processed in the brain, has long accompanied Ina Bornkessel. Back in Germany as a 17-year-old, she began studying computational linguistics. “In school, I was interested in both humanities and science, so computational linguistics seemed to be a good choice – a logical and mathematical approach to language,” says the scientist. But she quickly noticed that it was not quite right for her. Too application oriented, she decided: “I didn’t want to develop language programs for navigation systems and the like – I wanted to understand what goes on in the brain.” As a logical consequence, she changed her focus to general linguistics.

Gaining an understanding of how our brain deals with language, how it processes what we hear, is still an exciting goal for Bornkessel’s primary focus today. Incidentally, the initial spark for her scientific orientation also came from her home at the other end of the world: A visiting Australian professor at the University of Potsdam, where Bornkessel was studying at the time, had given a lecture on the languages of the aboriginal people. “The natives of Australia still speak an incredible number of different languages even today, and they function so very differently than the European languages with which we are familiar. I was curious how such a variety could even come about,” recalls the researcher. At this point, she realized that this phenomenon could be understood only by studying as many widely different languages as possible. This is an approach that has long been standard
in theoretical linguistics. For Ina Bornkessel, however, the question is not only one of language acquisition, but also one of how our brains process language. She is interested in understanding how we can process language so quickly, even while we are processing other information at the same time.

This approach is new. “There are more than 6,000 languages in the world, many of which exhibit vastly different properties,” says the Max Planck researcher. “I am interested in knowing whether there are common structures to which the brain responds – neuronal patterns that are identical for all languages.” Initially, it is the differences that aid in the search for these general principles. English and German, the two languages with which Bornkessel grew up, are good examples. At first glance, they are not that different at all. At least, that is what we Germans think, as we find it relatively easy to learn English. The matter is somewhat more complicated the other way around. German dative constructions, for instance, are quite a challenge for English speakers. Or the fact that German verbs can occur at the end of a sentence, which, incidentally, is also true for Japanese and Turkish. Under these circumstances, the meaning of a sentence can’t be understood – at least from a purely theoretical standpoint – until it has been fully uttered. And that is also what linguists assumed for a long time. In the 1980s, the concept of “head-driven” language processing prevailed. The head is considered to be the verb, which describes the action and thus gives the sentence its meaning. If it occurs at the end, the brain doesn’t assemble the content until everything has been said – or so many researchers believed at the time.

“The brain interprets what it hears – even while the speech is still being uttered. ‘Anything else would be ineffective and would lead to a delayed understanding of speech,’” is how the explanation goes. To do this, the brain uses certain structures that it already knows and that are repeated again and again in all languages. Or at least in those that have been studied to date. And the young Max Planck researcher also has experimental proof of this: she watches how the brain reacts to sentences and their small and not-so-small stumbling blocks. To do this, she uses electroencephalography (EEG) and measures her participants’ brain activity while they listen to or read various sentences. What is interesting about this is that, as long as nothing unusual happens, brain activity essentially always stays at the same level – as, for example, with the simple sentence “Peter mag Maria” (Peter likes Maria). Everything is straightforward here, and the standard sequence subject – predicate – object leaves practically no room for misunderstanding.

**Increased Neural Activity When Maria Acts**

But even when it gets slightly more complicated, such as in “Ich weiß, dass Peter Maria gefällt” (I know that Maria finds Peter appealing), the German brain has to strain a bit. The relationship has been inverted. Whereas, initially, the actor was Peter, in the last sentence, it is suddenly Maria – despite the fact that, at first glance, the structure hasn’t changed at all. As soon as the verb is uttered, the brain must therefore rethink the situation, reject the original interpretation and allow a new one. This is work and shows up in the EEG in the form of increased activity.

By comparing unproblematic sentences with others that are, at first glance, similar, but indeed trickier, Bornkessel and her colleagues discover what strategies our brain uses to surmount its difficult task of immediately interpreting what is heard, thus ensuring real-time language comprehension. Her hypothesis is as follows: In language, there are certain hierarchies that can be used for effective comprehension – features that mark certain words as taking priority over others. “Let us take nouns, for instance. Normally, the rule is that animates take priority over inanimates and thus determine the action,” says the researcher. She cites examples: “Der Gärtner streift den Zweig” (the gardener brushes against the branch) is just as simple as “Klaus fragt sich, welchen Zweig der Gärtner streifte” (Klaus wonders which gardener the branch gardener brushed against). The gardener is the animate entity, so it takes priority over the branch in the hierarchy and is – beyond a doubt – the active party.

But what about the following example: “Klaus fragt sich, welchen Gärtner der Zweig streifte” (Klaus wonders which gardener the branch gardener brushed against)? The gardener is the animate entity, so it takes priority over the branch in the hierarchy and is – beyond a doubt – the active party.

Checking the monitors: On the right, Ina Bornkessel watches a participant’s EEG during data acquisition. The left monitor shows the Chinese sentence the participant is reading.
Gärtnern” (which gardener – accusative). And our brain thus quickly recognizes that the inanimate entity is the actor here.

“We find these or similar patterns in all languages that we’ve studied to date,” says Ina Bornkessel. “This allows us to conclude that these are universal principles for language processing.” Of course we would need to study many further languages to be sure – especially those that are significantly more complicated because they deviate from the very obvious rules. Chinese, for example. Or Fore, which is spoken in the highlands of Papua New Guinea.

Here, the animacy hierarchy is somewhat stricter. If the words “man,” “pig” and “kill” occur in a Fore sentence, then, regardless of their sequence, the action is always initiated by the man. For the speakers of this language, humans always take priority over animals or inanimate objects – even though the pig is, of course, also capable of killing the man. “In German, we can express this alternative state of affairs very simply, but Fore speakers require completely different words and constructions,” explains Bornkessel. She also has a few other such puzzles to solve – and one can see how anxious she is to do just that.

Incidentally, the young neurolinguist is interested not only in when our brain must shift into a higher gear for language processing, but also in where this takes place in the brain. To do this, she uses functional magnetic resonance imaging (fMRI).

She explains the change in method thus: “With the EEG, we can determine only very generally whether there is more or less activity and when this activity occurs in time. However, this method is too imprecise for the ‘Where?’

In the brain, two regions are particularly important for language processing: Broca’s area and Wernicke’s area, both of which are located in the cerebral cortex. Scientists long thought that these two centers play different roles in language production and comprehension. “However, this idea is long outdated, and today we know that both are important for both speaking and understanding,” says Bornkessel. Accordingly, she sees increased activity in both areas in the fMRI when the participants lying in the scanner hear sentences being read to them, or when they read them themselves.

A VARIANT THAT MEANS MORE WORK

Still, there are major differences. Both brain regions appear to engage in different aspects of language comprehension, as the fMRI studies have shown. For example, a portion of Broca’s area is particularly challenged when a sentence does not follow the normal sequence and a noun that is lower on the hierarchy appears first, for instance an inanimate noun before an animate one – such as “Gestern wurde der Hut dem Gärtner gestohlen” (The hat was stolen from the gardener yesterday) instead of simply “Gestern wurde dem Gärtner der Hut gestohlen” (The gardener had his hat stolen yesterday). Both variants are possible, but the first is more unusual and means more work for the brain and especially Broca’s area.

Hierarchy issues activate Wernicke’s area, too. However, this center is responsible for the relationship between two participants in an event. It exhibits increased activity when the actor is not higher up in the hierarchy, as in the example sentence “Klaus fragte sich, welcher Zweig den Gärtner streifte,” (Klaus wondered which branch brushed against the gardener), where the inanimate object performs the action. Or even when both nouns are on the same hierarchy level, as in: “Gestern hat der Pirat die Prinzessin geraubt” (The pirate stole the princess yesterday). However, if the sentence were: “Gestern hat der Pirat den Schatz geraubt” (The pirate stole the treasure yesterday) – the actor is animate, the passive object is inanimate – then Wernicke’s area apparently finds nothing unusual about it and there is thus also no increased activity in the fMRI.

Incidentally, these findings were obtained in collaboration with the neurolinguistics research group at the Department of Germanic Linguistics of the University of Marburg – and this is true for much of Bornkessel’s work. This is where Matthias Schlesewsky works, with whom she shares far more than just a common research interest: the two scientists are married and make a good team in their private lives, too. “It’s great to have a partner with whom I can share my passion for neurolinguistics, and with whom I can collaborate so well,” says Bornkessel enthusiastically. But of course she can also switch that off and focus on very different things – such as travel, and not just to Tasmania. The researchers also like to hike, preferably above 2,000 meters. “Up there, I can really clear my head and can’t help but give my projects a rest – the body uses far too much energy at those altitudes,” says Ina Bornkessel. So she recharges her batteries on mountain summits, whether in the northern or southern hemisphere, and then converts this energy back into inspiring ideas for her work. **Stefanie Reinberger**
Carl Friedrich von Weizsäcker is regarded by many as the archetypal scientist with a sense of political responsibility. In the mid-1940s, recognizing the dangers inherent in maintaining a nuclear deterrent, he saw it as his duty to combine scientific knowledge with political action. With a desire to continue the previous Max Planck Director’s practice of provoking food for thought, the Vereinigung Deutscher Wissenschaftler (Federation of German Scientists, VDW), co-founded by him, held a conference in cooperation with institutes associated with the University of Hamburg to discuss Weizsäcker’s lifetime achievement and consider future perspectives.

The responsibility of the sciences: As clear and simple as the title of the first Carl Friedrich von Weizsäcker Forum may sound, it is also something of a paradox. Isn’t responsibility linked to individuals? To attribute responsibility to the sciences must therefore also mean that those engaged in scientific activities must act responsibly. But just what does that mean? Who determines what is responsible? And toward whom must one act responsibly?

For the VDW, the answer is straightforward. The renowned physicist and philosopher was, after all, their founder, and his actions set standards in the atomic age. Not least as the Director of the Max Planck Institute for Research into Conditions of Living in a Scientific and Technological World, founded specially for him in Starnberg in the early 1970s, he acquired a prominence that endures to this day.

In fact, his stature is maintained both by the VDW and by the Carl Friedrich von Weizsäcker Forum.
Center established in 2006 at the University of Hamburg. The first part of the forum featured former colleagues, students and employees who paid their own tribute to individual stages in the life and areas of activity of the great man: retired scientist Klaus Gottstein (33) of the Max Planck Institute for Physics looked back to the increasing and multi-faceted politicization of a number of German nuclear physicists in the post-war years, including Otto Hahn, Werner Heisenberg and, of course, Weizsäcker. Having touched on the subject in the Mainau Declarations at the conference of Nobel Prize Winners 1955 and 1956 – with no great response – it was a process that culminated in the Göttingen Declaration, published in 1957.

According to Gottstein, Weizsäcker apparently sought advice from Martin Buber, who had described the risk of war as a genuine moral issue and had already expressed warnings against the atomic bomb. In principle, the physicists were not addressed to anyone in particular and they contained no personal commitment. The Göttingen Declaration made up for these shortcomings and triggered a political shock wave in Germany. Politicians regarded the scientists’ action as sheer arrogance.


It was not usual at the time for scientists to involve themselves in politics. And yet, as historian Ilona Stöken-Kothen explained, it was because they were apolitical that these academics were perceived by the public as having such an authoritative voice in the political debate. She presented an impressive case study in which she quoted from comments made at the time that described the political opinions expressed in the Göttingen Declaration as an “appeal,” a “rebellen” and even an “upside of conscience” and a “moral bomb.” However she also dispelled a few myths: It was wrong, she maintained, to claim that Germany’s lack of an atomic bomb during the war was attributable to moral reasons. In fact, the Heereswaffenamt, the department in charge of military procurement, ceased to prioritize nuclear research because of the high cost.

“German nuclear weapons researchers had the simple good fortune to be spared the crisis of conscience over whether to build a bomb for the National Socialist regime,” she concluded. And she went on to describe the political responsibility touched on in the Göttingen Declaration as “half-hearted” and “ultimately dishonourable,” given that no reference was made to the inseparable link between the military and civilian uses of nuclear technology.

It was Horst-Eberhard Richter who neatly made the transition to “Responsibility in our own time,” as the second day of the forum was entitled. The 84-year-old psychoanalyst and peace scientist, as he describes himself, made a vehement plea for a moral crusade. Following the call of Weizsäcker’s 1967 speech on the abandonment of peace as a moral disease, in which he described the willingness to embrace peace as one of the strongest forces at the disposal of mankind, the suspension or atrophy of which was founded in a lack of peace with oneself, Richter pointed to the vast suspicion drawn upon themselves by those who, for example, in the debate about Red Army Faction terrorism in Germany, attempted not only to see the victim’s side, but also to express concern for the perpetrators. Advocates of an understanding and forgiveness were equally exposed to suspicions of betrayal in the environment of global terrorism post-September 11, and the response to Islamic militancy.

This despite the fact, Richter believed, that the military action, set in motion in the fight against evil, far exceeded the harm inflicted by the terrorists. Where, then, was the moral support for the demonstrably existing desire of so many people not to abandon peace? It would not be forthcoming from political circles: the list of public concerns compiled annually by German insurer R+V Versicherung was consistently headed by the fear that politicians were already overwhemed.

Hartmut Grallis, for one, had no doubt that politicians needed the support of scientists. Without the descriptive scenarios developed by researchers to augment their knowledge in the widest sense, politicians would be unable to come to any decisions, declared the retired Director of the Max Planck Institute for Meteorology and Deputy Chairman of the VDV. It was the responsibility of scientists to highlight their findings. Grallis was convinced that climate experts had not drawn attention to the greenhouse effect and the deteriorating ozone layer, the Kyoto Protocol would never have come about.

The only difference since Weizsäcker’s day was that mankind now faced different threats. The risks of the atomic age had since been amplified by issues like the loss of biodiversity and climate change – issues attributable not least to human lifestyles. It was hugely important to make young scientists aware of the responsibility incumbent upon them, Grallis continued, and the VDW was currently mounting a campaign for just that purpose. Initial surveys show that at least some young people view the consequences of research as equally all-embracing.

What is described as a new alumni initiative was launched at the 2007 General Meeting of the Max Planck Society. As part of this program, all former scientists and employees are invited to keep in contact with their institutes and with the Society as a whole, even after moving on to new pastures.

“We would like to welcome all alumni of our institutes and facilities to become part of the Max Planck Society once more. Together we can build a global Max Planck network through which to contribute and exchange ideas, experiences and contacts in the worlds of science, industry and politics,” said Max Planck President Peter Gruss on the launch of the new initiative.

Some institutes have been successfully involved in alumni activities for years, setting up institute friends and supporters groups and organizing regular meetings of former staff. MPS Administrative Headquarters now intends to support these activities on a wider basis and encourage all institutes to develop their own alumni programs. Thus far, a gratifying total of 55 institutes have expressed support and have appointed an alumni representative to coordinate alumni registration and organize programs at their respective institute. Other institutes have since also indicated their interest in joining in the initiative.

As a first step, since July 1, all former academic and non-academic staff have access to the Max Planck Society’s new communication platform, maxNet. Those attending the Annual Meeting in Kiel had an opportunity to take an initial look at this portal at the maxNet stand. maxNet offers alumni exclusive access to the latest news from the Max Planck Society and its institutes. They can also search for, and hopefully find out, other former colleagues they have met in the past, or even set up their own discussion forums, and update their profile data online.

For further details about the services maxNet offers and how to register, alumni can request a leaflet from their institute. For a personal atmosphere, alumni can find further information in a leaflet.


**Interview with Michael Kröher**

**“We are better than many people think”**

Michael Kröher holds a doctorate in medicine and has been a science journalist at various sources for many years. In his latest book, he analyzes the field of cutting-edge research and high technology in Germany, and draws some positive conclusions.

“German research exceeds its reputation,” says Kröher in his book *Wirtschaftsfaktor Wissen* (“Knowledge as an Economic Boom”). In addition to the German Research Council (DFG), the Helmholtz Association, the Fraunhofer-Gesellschaft and the Leibniz Association, Kröher also takes a detailed look at the Max Planck Society.

**MaxPlanckResearch:** What gave you the idea to write a book about the economic impact of knowledge?

**Michael Kröher:** In the past fifteen years in which I have been working as a science journalist, I have had so many exciting encounters with both research and researchers that I felt I had to put my experiences on paper. Since becoming an editor and reporter specializing in research and technology at *Wissenschaftswoche*, I have turned my attention particularly to the interface between business and science. After all, in the long term, research and development and the resulting advances in high technology are the only resource in the present century that can turn to in order to maintain its position at the forefront of leading economic nations. Long before the Cluster Initiative promoted by the Fraunhofer-Gesellschaft and the Federal Ministry of Research, it struck me that there were technology clusters developing in certain regions. I was interested to know what the attractions were. What prompted this cooperation between science and business? And what are the factors that determine why some technology centers succeed while others don’t?

**MaxPlanckResearch:** In your book, you identify eight centers of technology: Martinisried, Garching, Heidelberg, Hamburg, Jülich/Aachen, Berlin-Aldershof, Dresden and Stuttgart. What is their recipe for success?

**Michael Kröher:** There are primarily two factors that I consider to be pivotal. Firstly, research now can be effective only on a multi-dimensional level; in other words, if you want to succeed, you must think as well as act as part of a network. It is no good if basic, applied and industrial researchers just happen to know about one another. They have to cooperate on a coordinated, long-term basis and pursue industrial applications. It is lead to improved, marketable products or processes, such as a new manufacturing process. To do so, they need a clear overview of the value chain. Therefore, Max Planck scientists must consider what the practical results of their research may be. And secondly, success is absolutely dependent on working on an interdisciplinary and open-minded basis. Imagine you are a Max Planck scientist engaged in basic biotechnology research in the hopes of developing a new drug. Almost unintentionally, you discover that your biotechnology methods lend themselves to the production of, say, a fat solvent with vast potential for use in detergents and cleaning agents. What then need is the marketing flair to immediately strike a deal with an industrial partner.

**MaxPlanckResearch:** If you think back over policy research in Germany in the past ten years, what has changed?

**Michael Kröher:** There has been a deep-seated change of perception on all sides, both among politicians and at research institutions themselves. Let us take the Max Planck Society as an example: Twenty years ago, many of the Society’s scientists still concentrated closely on basic research. Nowadays, however, it is quite clear that the pursuit of basic research can no longer be conducted without a purpose in mind. The Society has to give something in return, in the form of research that culminates in some economic benefit. At the same time, the Harnack principle still applies at the MPS, which guarantees, in brief, that “We are the best that we can be.” Or consider the Helmholtz Association, which originated in 2001 with the merger of 15 research centers. Even if research budgets in Germany remain static in many instances, there is now a generous scope out there for innovative research. In many fields – for example in research into solar and other renewable energy sources, in materials science and nanotechnology and other optical technologies – Germany continues to lead the world. This is often the result of a particular inter-action between enthusiasts and open-minded scientists and the business community.

**MaxPlanckResearch:** What role do the universities play in front-line research in Germany?

**Michael Kröher:** Despite the Excellence Initiative, universities still lag behind non-university research institutions. However welcome the Excellence Initiative may be in adding momentum, given the rigid structures that exist, it will be a few years before any measurable successes are achieved. Fortunately, many German universities have already recognized that they have to live within their means. But compared with the budget available to the EBI Zurich, even the Excellence Initiative funds are just a drop in the ocean.

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**FLORIDA SHOWS INTEREST**

**An Institute on American Soil?**

The Max Planck Society has received an offer to establish its first foreign institute in the US. On September 11, Florida’s Palm Beach County unanimously proposed the sum of 86.9 million US dollars for the next 10 years. In coming weeks, it is expected that the State of Florida will contribute funds to complete the financing, and that concrete negotiations on the establishment of an institute will take place.

The county’s decision paved the way for the equally necessary approval by the State of Florida, which intends to boost the sum provided by the county to a total of 190 million dollars. This would facilitate the creation of a Max Planck Institute in the life sciences on the Jupiter Campus of Florida Atlantic University (FAU), in the immediate vicinity of the Scripps Research Institute.

“This decision is a great compliment for the Max Planck Society. We are very pleased that the county commissioners have demonstrated such great faith in us,” said Max Planck President Peter Gruss after the vote. With the recent addition of Scripps, and now perhaps also the Max Planck Society, Florida aims to quickly gain a place in the premier league of the world’s bio-technology hubs. The state hopes to attract yet further internationally renowned research institutions and biotech companies to the emerging center, thus enabling Florida to safeguard its long-term economic success. “The fact that those responsible for this development in Florida have specifically invited a German research organization as their sole partner from abroad represents a triumph for German science as a whole,” President Gruss declared.

The Scripps Research Institute, internationally renowned in the field of biomedicine, opened its doors on the Florida Atlantic University campus just three years ago. The prospect of a Max Planck Institute on a shared campus with Scripps is the primary reason for the Max Planck Society’s interest in Palm Beach County. “Scripps and Max Planck are a dream team for innovative basic research in biomedicine,” said Gruss. The offer extended to the Max Planck Society is also supported by the local Florida Atlantic University (FAU). The FAU, the fastest-growing university in the US, will be a key partner in educating junior researchers and will provide the land for the new construction.

The Senate of the Max Planck Society meets in November to discuss founding the new institute. Provided the Senate supports the idea and the State of Florida echoes the positive vote by the county and agrees to provide funding, actual contract negotiations can begin, and the institute could take up its work as early as 2008. The institute would eventually have three departments staffed by around 135 researchers from all over the world. At the same time, the Max Planck Society wants to offer a visiting scientist program and provide lab space for internationally renowned researchers to carry out their work.

“The Max Planck Florida institute would give us an independent foothold in the world’s most important country for science,” says Peter Gruss, who views the negotiations in the US as part of a wider internationalization of the Max Planck Society. “We want to export the Max Planck model for success worldwide and step up our international activities in Europe, the US and Asia.” In this context, forms of cooperation can range from Partner Institutes all the way to full-fledged Max Planck Institutes.
MAX PLANCK NEWS

MAX PLANCK COMMEMORATED: Imagine the look on the supermarket checkout girl’s face if you tried to pay for your shopping with a silver 10-euro coin emblazoned with the head of Max Planck. Well, it could happen – but not until after April 10 next year. That is the date on which the Bundesbank intends to issue an 18-gram commemorative coin to celebrate the 150th birthday of the physicist and Nobel Prize winner. In common with most all commemorative coins, it will be legal tender, at least in Germany, though it is more likely that Max Planck’s sterling silver likeness will end up in the hands of collectors. The design for the coin was created by artist Michael Otto. It shows Max Planck’s head in profile, with the thermal radiation spectrum that he researched in the background. On the reverse is a stylized eagle. The Nobel laureate’s dictum – “Insight must precede application” – will be traced on the rim of the coin.

STEELS OF TOMORROW: Work is in cooperation with the RWTH Aachen University of Technology, the Max Planck Institute for Iron Research in Düsseldorf is using computer-based quantum mechanics to develop new steels. A special research department codenamed SFB 763 has been set up for that purpose at RWTH in the support of the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG). The project’s full name is “Steel – ab initio: Quantum-mechanics-guided design of new basic iron materials.” Wolfgang Birk of the Institute for Ferrous Metallurgy at RWTH and Max Planck Director Dirk Raabe will head the project, which is initially set to run for a period of four years. Three of the four departments at the MPI and various other university departments will have a hand in the research. SFB 763 will address two basic questions: What form might the design of a new class of structural materials take? And which methods might lend themselves to a material development process based on so-called ab initio calculations? The intention is to investigate a system composed of iron, manganese and carbon that must exhibit particular properties: it must be easy to work, exhibit very high strength and be more universally applicable with substantially cheaper to manufacture than nickel-alloyed stainless steels. It is hoped that the close cooperation between physicists and engineers will accelerate the development of special steels that meet the most stringent safety requirements despite being lighter in weight, thereby reducing the fuel consumed by aircraft and motor vehicles.

NEUROPROSTHETICS RESEARCHERS HONOR: The Gertrud Reemtsma Foundation, administered in trust by the Max Planck Society, recently presented the Zülch Prize for the 15th time in a row. The 50,000-euro award for exceptional achievements in basic neurological research is shared this year by Greame M. Clark of the University of Melbourne and John P. Donoghue of Brown University in Providence, USA. Both scientists work in the field of neuroprosthetics – a discipline that aims to develop technical systems to compensate for functional defects in the human nervous system. Clark was given the award for his pioneering work on cochlea implants for patients suffering from profound deafness, the first neuroprostheses to be used in human subjects. Neuroscientist Donoghue was singlehandedly put out for his research into how the brain converts thoughts into action. Resolving this problem was an essential first step in his development of neuroprostheses intended to serve as interfaces between brain and machine, thereby enabling paralyzed patients to control machines by willpower alone. The prize, presented in late August in Cologne, is given in memory of the neurologist Klaus Joachim Zülch, who was Gertrud Reemtsma’s brother and Director of the Cologne Department for Neurology of the Max Planck Institute for Brain Research in Frankfurt.

TURNING UP THE HEAT ON FUSION: Even before work starts on the ITER test plant in Cadarache in southern France, there is good news for the participating Max Planck Institute for Plasma Physics. In a change from previous plans, a high-frequency ion source developed at the institute has been selected as a particularly robust, low-maintenance means of heating the plasma to be ignited in the fusion power plant. The decision of the ITER will address an international competition of experts. “This is a great success for the IPP, which comes as a just reward after years of development work,” said a delighted departmental manager, Eckehart Sperer. ITER is the next big step in global fusion research. In a joint venture involving seven partners (Europe, Japan, USA, Russia, China, India and South Korea), the plant is intended to demonstrate that an energy-yielding fusion fire is a genuine possibility. The expected output of 500 megawatts will exceed the energy needed to heat the plasma by a factor of ten.

Research Establishments of the Max Planck Society

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Gerhard Ertl wasn’t expecting quite so much attention on his 71st birthday. Of course the Director emeritus of the Department of Physical Chemistry at the Fritz Haber Institute of the Max Planck Society was long considered by peers to be a strong candidate. His research laid the foundations for modern surface chemistry and thus created the know-how needed to optimize, for instance, fuel cells and catalysts. When he actually received the call from Stockholm, though, Ertl was surprised and overwhelmed. For 20 long minutes before the official announcement, he was not allowed to share his news with anyone – not even his wife Barbara. As it turns out, those 20 minutes were the proverbial calm before the storm: when the Nobel Committee announced him as the winner of this year’s Nobel Prize in chemistry, he was inundated with a deluge of media attention. Nevertheless, the newly minted Nobel laureate in chemistry – who is actually a physicist – is imperturbable. Perhaps because he has often opened himself up for new things over the course of his life. Born in Stuttgart in 1936, he first studied physics at the Technical University of Stuttgart and the University of Paris. After completing his degree, he continued his studies at the Technical University of Munich, where he obtained his doctorate. He then took a job there as an assistant at the Institute of Physical Chemistry, and acquired his German post-doctoral lecturing qualification in 1967. The following year, he accepted an offer from the Technical University of Hanover, and in 1973, from Ludwig Maximilians University in Munich, where he remained until 1986 – interrupted only by several visiting professorships in the US. Finally, in 1986, Gerhard Ertl was appointed a Scientific Member and Director of the Department of Physical Chemistry at the Fritz Haber Institute of the Max Planck Society in Berlin.