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Photo Editor: Susanne Schauer (-195)

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Someone did quite a job tidying up here. Even the curtains are all pushed neatly to the same side. The blue of the individual image elements harmonizes almost too well. But wait: Couldn’t they have also set the chair backs at the same level? And why are the number signs on the booths so mixed up? Where are we, anyway? In a deserted call center? At a polling station? Is science being done here when no one is looking? Let’s reveal the secret: The image shows the oldest lab for experimental economic research in Europe, the BonnEconLab. Scientists have been studying human economic behavior here since as long ago as 1984. To date, nearly 30,000 people have participated in their experiments. The Max Planck Institute for Research on Collective Goods also regularly uses the lab.

Research subjects with a penchant for experiment can earn money by “playing” the test games at the BonnEconLab. Whether as market participants, as bidders in an auction, or in negotiations: the test subjects continually make more or less successful decisions. Their success, on which the final reward for the individual participants depends, is influenced to a substantial degree by the decisions of their fellow players. Chance also plays a role – just like in real life.

Experimental economics was long a controversial subject within the field of economics. With game theory came the first economic experiments in the 1960s. But people were slow to realize that experimental findings must be used more and more as a basis for economic research. Today, experimentation is a recognized research method in economics – and German researchers were at the forefront right from the start.
Crossroads: The pharmaceutical industry must advance the development of new drugs.

Nanoelectronics

Calculating with Carbon
Flexible, printable and affordable – these are the properties molecular electronics promise. Scientists at the Max Planck Institute for Polymer Research are paving the way to optimizing organic substances for use in solar cells, light-emitting diodes and memory chips, and are using molecular materials to develop electronic components for the future.

Quantum World in a Cube
Nanostructures surprise scientists again and again with exotic quantum effects. Using ultrasensitive instruments, experts at the Max Planck Institute for Solid State Research explore the peculiar properties of electrons in the tiniest dimensions. They are interested in, for example, current transport without resistance in superconducting nanostructures, and the fundamentals of spintronics.

Chips from a Sheet
Graphene is considered a versatile superhero of materials science. With a thickness of just one atomic layer, these carbon layers have extraordinary mechanical and electronic properties. How the chemical structure determines the material’s physical behavior is one of the questions scientists at the Max Planck Institutes for Polymer Research and for Solid State Research are investigating.

ON THE COVER: The network of carbon atoms in graphene is reminiscent of chicken wire. The irregular wave structure is thought to be one possible reason why graphene is so stable. It’s more tear-resistant than any other material, and possesses unusual electronic properties.

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The pharmaceutical industry is shying away from the development of new drugs – especially when it comes to diseases affecting people in developing countries. Peter H. Seeberger analyzes the reasons for this and presents some approaches to solving the problem.

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The sculpins at the Max Planck Institute for Evolutionary Biology are no beauties. Nevertheless, these fish, which were first discovered in the Lower Rhine in the 1990s, fascinate researchers.

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It was difficult to determine whether the government of Colombia harmed Ecuadorian farmers by spraying herbicides on coca plantations near the border. Scientists at the Max Planck Institute for Dynamics of Complex Technical Systems simulated how the substances drift.

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Vietnamese markets aren’t just places for goods to change hands; they also comprise complex webs of social relationships and political structures. These aspects are a key focus of researchers at the Max Planck Institute for Social Anthropology in Halle.

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PHOTO CREDITS:
Photos: Denise Vernillo, dpa Picture-Alliance, corbis (left to right)
The Max Planck Society has the freedom and the mandate, each time a senior scientist retires, to review its orientation and address topics that are particularly innovative and full of promise. This is part of the scientific inheritance bequeathed to us as the successor to the Kaiser Wilhelm Society. Our aim is to be pathfinders in unknown scientific territory – after all, now that all of the continents on our planet have been mapped, only science remains terra incognita.

It isn’t imperative that we found new institutes to pursue this goal. Unbound as we are by the broader tasks of universities – a central tenet of Adolf von Harnack’s founding concept for the Kaiser Wilhelm Society – the Max Planck Society can renew itself at will. And it does, as the following figures demonstrate: some 80 percent of the almost 200 successor appointments made during my term of office have been in areas of research other than those addressed by the retiring predecessors.

Five institutes have even undergone a complete reorientation, such as the Max Planck Institute for Metals Research in Stuttgart, which now combines expertise in biology and in the computer and materials sciences, and changed its name to the Max Planck Institute for Intelligent Systems. Or perhaps the Max Planck Institute for the Study of Religious and Ethnic Diversity in Göttingen, which emerged from the former Max Planck Institute for History and now addresses such future-oriented issues as international migration and cosmopolitanism and multiculturalism in the world’s major cities.

However, making an appointment in a new area of research, let alone reorienting an entire institute, requires careful consideration. Each new field must be sustainable for 20 to 25 years. It is therefore a matter of identifying those individuals who can be guaranteed to adopt a particularly imaginative thematic and methodological approach to their particular areas of research. The Perspectives Commissions of the three scientific Sections of the Max Planck Society are thus tasked with deliberating at regular intervals on both new areas of research and new personalities.

Competition for the world’s best minds has increased perceptibly. The relatively small group of scientists of excellent caliber now stands in stark contrast to the huge demand on the part of international research organizations, particularly in the US, but also in other European countries. And of course the number of potential candidates is very limited in some research fields anyway.

Despite a rejection rate of almost 30 percent – in which we differ very little from other cutting-edge institutions, such as Harvard – the Max Planck Society remains a very successful competitor: almost half of those appointed since 2002 come from abroad – including some German passport holders – from such prominent research institutions as Princeton, Caltech, Yale, and the Universities of California and Tokyo, but also from our European competitors such as Oxford, Cambridge and ETH Zurich.

“How good the research work is in any given country,” wrote one of my predecessors, Hans Zacher, “is dependent on the talent of its researchers and the genius of the
best of them. However, how good the researchers are, and the extent to which the geniuses among them are able to unfold their full potential, is dependent on the structures within which they work, on the resources available to them, and on the freedoms that society allows them."

In a competitive environment, all of these factors must be attractive. We know from studies that small to medium-sized units are particularly well suited to stimulating creativity. But these units must be embedded in a wider context, so proximity to the university environment is of great importance to our Max Planck institutes. Not primarily as a source of personnel – the relationships, the atmosphere and the contact with the faculties are far more important. Just how fruitful this is has been demonstrated time and again by our centers of excellence.

But for all the care that is taken in selecting subjects, scientists and locations – a Nobel Prize is something that can’t be planned for! The idea that these prizes go mainly to the United States can safely be dispelled as a myth: the leading scientific nations in Europe are the United Kingdom, Germany, France, Sweden and Switzerland, and together they have just as many Nobel laureates as the US. If we include the rest of Europe, the total is a hundred more.

Of course, the number of Nobel laureates is only a limited reflection of scientific capability. The number of citations per publication, on the other hand, is a very helpful scale by which to measure the importance and influence of the scientific performance of a nation or organization. After all, works of great scientific importance are cited more frequently than those of lesser significance. It is a source of particular pleasure to me that the Max Planck Society’s researchers not only succeed in publishing papers of a consistently high standard, but that we rank second only to Harvard in the top 1% of the most frequently cited publications in the natural sciences.

After all, what matters is quality, not quantity, as witnessed by the criticism recently expressed by scientists in The Lancet, and now also making an appearance in the German media, that too many of the products of research are lacking in importance. In making appointments, the Max Planck Society has long since ceased to focus on numbers of publications. The sole deciding factor is whether the candidate is genuinely successful in exploring new scientific territory. We aim to continue to be the pathfinders in terra incognita.

Peter Gruss,
President of the Max Planck Society
Partners in Research

Max Planck Society and RIKEN celebrate the 30th anniversary of their cooperation

Around 150 participants recently came together – including the Presidents of both research organizations, Peter Gruss and Ryoji Noyori, as well as leading scientists and high-ranking representatives from politics and business. The ceremony, which took place at the Industry Club of Japan in Tokyo, was opened by RIKEN’s President, who is also the Nobel Prize laureate in Chemistry 2001. Noyori pointed out that the research organization he heads was founded in 1917 and modeled on the Kaiser Wilhelm Society, and today continues to be based on the example of the Max Planck Society. He referred to the fact that a new evaluation has underscored the outstanding role of RIKEN within the Japanese science system. The institutional cooperation between RIKEN and the Max Planck Society goes back to 1984 when Presidents Tatuoki Miyazima and Reimar Lüst concluded a framework agreement.

Ten years after the “Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities” was first adopted, this Open Access initiative launched by the Max Planck Society has found a strong international following. At the 10th anniversary conference in Berlin, the declaration was also signed by representatives of the Yad Vashem Holocaust Memorial and the Prussian Cultural Heritage Foundation, increasing the number of signatories to more than 460. "This is a remarkable development, but Open Access is not a surefire success just yet,” said Max Planck President Peter Gruss. The Mission Statement presented at the conference is to act as a guideline for the transition to Open Access. One of the key aspects is to maintain high quality standards and to develop them even further. "When faced with the glut of both information and disinformation on the Internet, it is particularly important for it to be clear which articles meet the most stringent demands of science,” emphasized Gruss. To drive forward the international exchange against this backdrop, the Max Planck Society will continue to co-organize follow-up conferences on the “Berlin Declaration,” but on a biannual basis.

At the Open Access Conference in Berlin, President Peter Gruss takes the opportunity to engage in a lively exchange.

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Warm handshake: RIKEN President Ryoji Noyori (left) welcomes Max Planck President Peter Gruss at the Industry Club in Tokyo.

Tailwind for Free Knowledge on the Net

More than 200 participants from 40 countries at the Open Access anniversary conference in Berlin

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“The Arctic Sunrise is no isolated case”

Conflict surrounding the Greenpeace icebreaker has repercussions for international law

It was a thriller in the Arctic Ocean: In the fall of 2013, Russian Security Service vessels seized the Greenpeace icebreaker ARCTIC SUNRISE during a protest against the Prirazlomnaya oil platform and held the 30-person crew in detention for some time. In response to an application by the Netherlands, which is the ship’s flag state, the International Tribunal for the Law of the Sea (ITLOS) ruled that Russia was to release the ship, along with its crew, against bail of 3.6 million euros. Russia delayed this for a considerable time. The crew members were eventually allowed to leave the country shortly after Christmas, but the ship was still being held in January. We interviewed Rüdiger Wolfrum from the Max Planck Institute for Comparative Public Law and International Law, who was already president of ITLOS at the time, and also one of the judges on the tribunal that passed the current ruling.

Mr. Wolfrum, the media maintains that Russia doesn’t accept the tribunal’s verdict. This sounds like a violation of international law. What is your view?

Rüdiger Wolfrum: In fact, I consider statements like this to be greatly exaggerated. Russia has its own position, and of course there is a conflict. In any case, no final verdict has yet been passed, and the case will be decided before a court of arbitration. In a public hearing following a request for provisional measures, ITLOS’s role was to determine whether such measures were needed to protect the rights of the parties until the court of arbitration could be set up. This involved two key questions that, though of a procedural nature, are of extremely far-reaching significance.

What are these questions?
From the outset, Russia said that it would not take part in the negotiations. It based this on a declaration it had made during ratification of the United Nations Convention on the Law of the Sea (UNCLOS). It was therefore necessary to clarify whether the soon-to-be-established court of arbitration would be rendered incompetent by this declaration. ITLOS refuted this, based on exceptionally brief grounds. It then considered the question of what it means if one party doesn’t appear. Here, the judges’ deliberations were longer. Two points need emphasizing: first, that a party continues to be a party to the proceedings even if it fails to appear, and second, that it is bound by the court’s ruling.

Does this ruling set a precedent?
Indeed it does. Even if there have been similar cases, no court in this form has yet grappled so profoundly with the question of what a failure to appear really means. In this regard, ITLOS made a decision that plays an important role in the future of international law and that will encourage other courts to pass exactly the same ruling in similar situations.

Why is Russia refusing to appear anyway?
With its declaration on the ratification, Russia wants to stop any coercive measures that it takes within its exclusive economic zone from being challenged internationally. And this can’t be done in such broad strokes – it applies only to fishing and research. The ARCTIC SUNRISE was doing neither. What is important in this context is the general ruling of the UNCLOS. It distinguishes between coastal waters, where a coastal state is fully competent to pass and enforce laws, and the aforementioned economic zone, in which the coastal state has only limited rights to do so. The situation differs only in the area surrounding artificial structures located within this zone, such as oil rigs: the coastal state can set up safety zones within a 500-meter radius of these structures, where it retains full competence, including policing powers.

And is this particular point significant in the present case?
Yes, because it now appears that the ARCTIC SUNRISE didn’t enter the safety zone around the oil rig; at least, the ship was outside it when it was seized. And this, of course, raises the question: Was Russia within its rights to seize the ship? ITLOS commented only indirectly on this: while it assumed that the legal position is unclear in this respect – that being up to the court of arbitration to decide – it did still see problems as regards the seizure of the ship in the economic zone. For this reason, and on humanitarian grounds, it ordered the release of the ship and crew. This is a conclusion with far-reaching consequences, and will not be welcomed unreservedly by all coastal states. There is a tendency to extend coastal state competencies, particularly policing powers, into the exclusive economic zone.

So, does ITLOS see a bias in favor of Greenpeace?
I wouldn’t say so; both sides have legal arguments in their favor. Before the ARCTIC SUNRISE was stopped, its inflatable boats had entered the safety zone – two people were attempting to climb onto the rig. They were apprehended and brought back on board. Moreover, the ARCTIC SUNRISE is no isolated case. Greenpeace has taken a similar stand against a series of oil drilling operations in the Arctic. There are national rulings that prohibit Greenpeace from entering the safety zone of a platform off the coast of Greenland.

What is the next step in this specific case?
I’m assuming that, having released the crew, Russia will also hand over the ship, fully accepting the ITLOS ruling on this matter. But no official statement has been issued as yet. Russia can’t stop the court of arbitration from being set up. The procedure – including the appointment of the arbitrators – is designed so that the ITLOS President determines the arbitrators, who, in principle, are to be jointly appointed by both parties. There is thus an anti-blocking mechanism in place that stops one party from impeding the dispute resolution procedure by failing to appear.

Interview: Jens Eschert
Breaking New Ground in Latin America

Laying foundations for cooperation with Colombia and Peru/Max Planck office opened in Buenos Aires

On his first visit to the South American countries of Peru and Colombia, which are increasing their focus on research and development, Max Planck President Peter Gruss signed a Memorandum of Understanding with the research councils of both nations. This sets up a legal framework that allows interested Max Planck institutes to build up cooperative networks in these countries. “These states are showing a lot of interest. They are seeking advice and models for establishing their own research structures,” said the President. The plan is to support evaluation of the research system with the aid of an international committee of experts, or to set up national scholarships allowing doctoral students and postdocs to take up residencies at Max Planck institutes in Germany. The Max Planck Society is also seeking to expand its involvement in Argentina, Brazil, Chile and Mexico, and has opened a Latin America office in Buenos Aires with this aim in mind.

Wonders of Youthful Research

Winners of a junior research competition experience the daily life of a scientist

The 2013 and 2012 winners in the Physics category of Germany’s junior science competition Jugend forscht already accepted their prize money, donated by the Max Planck Society, during the competition. Now, as an additional “gift,” the winners of the State rounds and the all-Germany final also got the chance to gather authentic insight into a scientist’s daily life on a trip to Munich: doctoral students at the Max Planck Institutes of Quantum Optics, for Extraterrestrial Physics and for Astrophysics in Garching gave the prizewinners a guided tour of their labs and workshops. Using their actual experimental setups, the researchers directly demonstrated what they were investigating in their current dissertation projects – not exactly easily digestible fare for the 22 rising science stars, all aged between 15 and 20. Undeterred, they followed everything closely, interested and visibly impressed. They also learned how doctoral students finance their lives, how important and stimulating it is to work in a team with fellow scientists, and how the results of their research are published. The many exotic postcards pinned to the bulletin board at the Max Planck Institute of Quantum Optics proved that research trips and conferences can take scientists to many remote corners of the earth.

The young scientists looked particularly impressed by experimental setups at the Max Planck Institute of Quantum Optics.
Black Holes and Gravitational Waves

European Space Agency selects major missions with key contributions from Max Planck scientists

How were the large-scale structures we see today formed from ordinary matter? How did black holes grow, and what was their impact on the universe? These are some of the most important questions of modern astrophysics. And the next major European Space Agency (ESA) mission could provide the answers we need. “We are very happy that ESA has chosen ‘The Hot and Energetic Universe’ as one of its main projects,” says Kirpal Nandra, Director at the Max Planck Institute for Extraterrestrial Physics. Nandra heads an international collaboration that proposed the topic, and has already drawn up plans for an X-ray observatory called Athena (Advanced Telescope for High-Energy Astrophysics). Someone else is just as happy, namely Karsten Danzmann, Director at the Max Planck Institute for Gravitational Physics and spokesman of the eLISA (evolved Laser Interferometer Space Antenna) mission that the ESA is pursuing as part of its “Gravitational Universe” project. The space-based observatory is going to detect gravitational waves, helping to resolve fundamental astrophysical questions about the Big Bang and the evolution of the universe.

Space scout: While Athena (top) is to trace black holes and large-scale structures, the three eLISA mission satellites will be listening for gravitational waves.

On the Net

Bienvenidos a Alemania
Excellent doctoral students and post-docs from Spain, who are no older than 30 or 35 years of age, respectively, can now apply for a research residency at a Max Planck Institute. The programme, which was initiated on the occasion of the Prince of Asturias Award to the Max Planck Society in recognition of its international cooperation, provides the young researchers with the unique opportunity to establish scientific contacts in Germany. Closing date for the nomination is 31 May 2014. www.mpg.de/8034988/Max-Planck_Asturias-Award-Mobility-Programme

Colorful University Life
When Nuno Maulide’s Research Group moved from the Max-Planck-Institut für Kohlenforschung (coal research) to the University of Vienna, Desislava Petkova was one of those who also came along to the Austrian capital. In her contribution to the “Univienna bloggt” blog portal, she is now introducing her international team and its research projects—a good start in a new place. On the blog portal, researchers, students and alumni tell colorful stories from the university and get a chance to network with each other. A smart color-coding system means that readers can tell right away who is writing at any given time. http://blog.univie.ac.at/one-for-all-and-all-for-one

History of Emotions
Feelings such as fear, anger and love motivate or inhibit us in our actions. Emotions are learned socially and formed by culture, and they can change: they have a history. But how can the history of emotions be researched? What sources, questions and methods can help? Scientists at Berlin’s Max Planck Institute for Human Development explain this on their new web page. They analyze concrete sources, giving the reader insights into their research. www.history-of-emotions.mpg.de/en
A Prescription for New Drugs

During the 20th century, the pharmaceutical industry made crucial strides in advancing drug development. In recent times, however, the sector has seen noticeable cost-related cutbacks in research activity. We urgently need new drugs for the treatment of cancer, dementia and many other diseases. In developing countries, the problem is a matter of life and death. Our author pleads for a radical rethinking of the drug development system, and for the involvement of basic research.

TEXT PETER H. SEEBERGER

Life expectancy in Germany has almost doubled since 1900, increasing from 70 to 80 years between 1960 and 1980 alone. Better hygiene and nutrition played a very big part in this development. Another factor is clearly the improvement in medical care. Growing numbers of new drugs have brought an end to our fear of dying from previously fatal conditions, such as bacterial infections. Vaccines now shield us from viral and bacterial diseases like polio. Even conditions that were considered fatal until recently, such as HIV/AIDS, today no longer carry an automatic death sentence.

The pharmaceutical industry has driven the development of various drugs since the early 20th century. During this period, due to its role in the development of numerous drugs, Germany earned itself the moniker of “pharmacy to the world” and became a model for the sector in many other countries. However, considering the overall contribution of the pharmaceutical industry’s products to the wellbeing of the population, it’s surprising how unpopular the sector is. Surveys reveal that car manufacturers, for example, are held in much higher esteem.

The pharmaceutical industry is viewed as rich, powerful and devious. Admittedly, this reputation isn’t entirely undeserved. Denouncing its transgressions and preventing future mistakes is clearly the right thing to do. However, criticism of Bayer, Sanofi and other companies must not cause us to lose sight of the bigger picture. The development of the pharmaceutical sector is a cause for concern.

At the global level, the pharmaceutical industry is in the throes of a huge crisis that has been under way for a decade. Though the pharmaceutical giants are still pulling in big profits, they are increasingly cannibalizing their own scientific substance. The question arises here, of course, as to whether the wellbeing of very profitable companies should really be of concern to society. But the fact is that work on the development of new drugs and vaccines is waning – a situation that is clearly a matter of concern for the general public.

The problem has its roots in the fact that drug development is an increasingly risky and therefore expensive business. The costs currently range between 500 million and 1.3 billion euros per drug or vaccine. There are many reasons for this explosion in costs. First, the “simple” drugs are already available on the
We could be forgiven for believing that a pill already exists for every conceivable ill. Yet we urgently need new drugs for the treatment of cancer, dementia and other diseases. The problem is even more severe in developing countries.
market, and second, thanks to scientific progress, the drug development process has become more complicated. Moreover, the availability of better analytical methods means that the regulatory authorities exercise greater control over development and production processes.

This has serious impacts on company policies: pharmaceutical concerns currently concentrate on the development of blockbuster drugs—that is, drugs that earn them over one billion euros per year—mostly because they cure or alleviate very common conditions in rich industrialized countries. Such drugs alone enable the companies to achieve good returns within a matter of years—until the patent expires. The transformation of fatal conditions into chronic ones is popular with the companies, as patients are then forced to take a particular medication for a very long time.

For reasons of cost, diseases like malaria, which affect and kill people mainly in newly industrialized and developing countries, aren’t attractive for the pharmaceutical industry. The same applies to the marketing of expensive drugs in countries with less purchasing power. As a result, many important drugs remain unaffordable for the majority of people in developing countries.

A solution that is often called for (and that was implemented by the state in India) is to set aside existing patents and subsidize companies that produce cheap imitation products known as generics. This approach is entirely understandable from the perspective of governments like that of India. And it is very effective in the short term. However, the pharmaceutical companies in industrialized countries will be less likely to engage in costly research in the future if they know that the fruits of this research are going to be expropriated in some locations. The newly industrialized countries haven’t yet spawned any innovative pharmaceutical companies that are developing new drugs aimed at solving the region’s health problems. There is reason to hope that this situation will change at some stage. In the meantime, however, there is no other solution in sight apart from generics—and even these are often unavailable.

Cancer drugs are a good example of the gap that exists between industrialized and newly industrialized countries in this regard. In Europe, one in every three drugs introduced to the market is a cancer drug. “New” doesn’t necessarily mean considerably better in this context; often what is involved is merely a minimal change over existing drugs. There are around half a million cancer patients in Germany each year whose treatment with these new products costs around 80,000 euros per patient per year.

This astonishing volume of new drugs—between 600 and 800 are estimated to be in development—is due, not to an increase in the number of cancer cases or the improvement in treatment methods, but quite simply to market forces. The market is the mechanism that controls pharmaceutical research, supply and production. Although cancer drugs account for just 2 percent of the medicines prescribed, they are responsible for 25 percent of health insurance companies’ drug costs. This is the reason why there are a lot of new drugs on the market, even if, in many instances, they don’t represent any fundamental progress in terms of cancer treatment.

The exact opposite situation prevails in the newly industrialized and developing countries. As is the case in the industrialized countries, breast and cervical cancer are the most common forms of cancer in women there. The treatment options and drugs available in the industrialized nations are good. In Africa, in contrast, being diagnosed with one of these cancers is tantamount to being handed a death sentence. Following diagnosis, if one is made at all, patients live for only around four months on average—and they don’t receive any kind of treatment. Very few patients in African countries can afford the cancer drugs available in the industrialized world.

A similar situation may be observed in China and Vietnam, where, due to improving living conditions and healthcare, people are living longer and there has been a sharp rise in the number of people developing cancer. Here, too, the market controls the volume of pharmaceutical products available. As almost nobody can afford the expensive drugs available in the industrialized countries, and there are also no health insurance companies, there are few cancer drugs on offer in these countries.

The idea that the market will regulate everything is thus both right and wrong. The market is, indeed,
the mechanism that regulates the pharmaceutical sector, but this type of regulation isn’t always good from an overall systemic perspective. A minimum level of cancer drug supplies for developing and newly industrialized countries would be extremely useful. However, this would require the availability of extremely cheap cancer drugs. Such drugs aren’t being developed by the pharmaceutical companies in the industrialized countries, as cheap drugs don’t have high profit margins.

Malaria drugs, which are produced from the active ingredient and plant extract artemisinin, are also effective against cancer. Artemisinin-based malaria therapy costs around one euro. Clinical studies have been available for around ten years now that show that artemisinin is similarly effective at treating many types of cancer as current cancer drugs.

However, none of the pharmaceutical companies have set about licensing artemisinin derivatives as cancer drugs because the manufacturer would have to bear the high cost of the clinical licensing phases, but wouldn’t ultimately be able to file an effective patent, given that the active ingredient is already licensed as a malaria drug.

The market economy logic thus hinders the researching and licensing of a cancer drug that would be suitable for use in large numbers of patients in Africa, Asia and, ultimately, industrialized countries as well.

This dysfunction isn’t the result of the sinister machinations of evil people working in greedy pharmaceutical concerns. Nevertheless, it isn’t enough to simply acknowledge the existence of such anomalies with a shrug of the shoulders. The identification of innovative solutions to this problem requires political and scientific intelligence. One possible conclusion is that very different approaches and solutions are needed for different societal conditions. It may be assumed that the pharmaceutical industry with a uniform research system aimed at meeting the needs of the entire world isn’t the best solution.

To return to the situation in the industrialized countries, a process of consolidation may also be observed as another effect of the high drug development costs combined with the pressure of the financial markets. Bigger and bigger pharmaceutical groups have emerged with a view to exploiting the synergies between companies: Bayer swallowed up Schering AG, and Sanofi and Aventis merged, while Aventis itself was the result of the merger between Hoechst and Rhône-Poulenc. As the size of the conglomerates and their market values have risen, so, too, has the importance of shareholder value in the pharmaceutical industry.

Many companies were optimized with an eye to the balance sheets: from an economic perspective, research on new drugs is a risk that must be minimized. This could be achieved, for example, by transferring almost all segments of the drug development value chain to low-wage countries. Yes, that saved on costs. But it was a Pyrrhic victory, as it also resulted in the large-scale loss of highly skilled employees in industrialized countries.

Admittedly, cutting research budgets, for example closing central laboratories, is the least conspicuous measure in the short term. In the long term, however, this strategy threatens the very survival of the firms. For some time now, companies like Pfizer haven’t launched any new drugs and have been living entirely off their acquisitions, as their own development pipelines were empty. Nothing ventured, nothing gained! In an ideal world, a pharmaceutical company should be more than a bank with an R&D department.

The fact that many pharmaceutical concerns continue to rake in the sales is mainly due to the assimilation of successful products through the takeover of other companies. This conceals the major underlying trend, which is that the outlook for the entire sector is precarious. Germany’s “pharmacy to the world” is closing down. Generics are being produced cheaply abroad, and tens of thousands of highly skilled jobs have already been lost – in Europe and the US, too – for example at Merck, Pfizer, AstraZeneca and almost every other pharmaceutical company.

Of course, the management boards of most large pharmaceutical concerns recognize the enormous challenges they face, and are trying to counteract the trends and find ways to operate profitably in the long term. However, the circumstances are anything but simple: as demonstrated by various failed attempts in the past decade, it’s extremely difficult to develop new drugs with high sales while simultaneously sat-

Products that have few expectations riding on them often achieve huge commercial success.
ifying the expectations of the financial markets. The pharmaceutical giants also tend to obey a kind of herd instinct and follow certain fashions.

For example, over the past decade, several companies invested billions in RNAi technology, which, following great initial hopes, has, as yet, yielded no success. And products that have few expectations riding on them often achieve huge commercial success. Whereas, up to the year 2000, the rule of thumb was that, despite being an effective resource on the level of national economies, vaccines could yield little corporate profit, this thinking changed when annual sales of around five million US dollars came in from Pfizer’s pneumococcal vaccine Prevnar (developed by Wyeth). Suddenly, other vaccines became commercially viable products if they targeted wealthy customers. Several vaccine companies have therefore been acquired by larger pharmaceutical concerns in the past five years.

Companies are currently trying to reduce their own research activities to a minimum to keep costs and risks low, the idea being that the discovery of innovative therapeutic and diagnostic concepts should take place in research institutes and small companies. The plan consists in purchasing promising compounds and technologies when the risks are manageable. This means that the price will be higher, but the pharmaceutical concerns can exploit their strengths: experience in clinical trials and drug development – but no longer in drug discovery.

The enormous costs of the late development phase can be borne only by large companies with deep pockets. The risks associated with this approach are, of course, the lack of control over the early development phase and the danger of paying too much in the competition for the best projects.

Action is urgently called for: what we need are new drugs for the treatment of cancer, dementia and many other diseases. It’s a matter of life or death in developing countries: they need vaccines mainly for malaria, HIV/AIDS and bacterial diseases. It has long been accepted that, contrary to the cynical view, a good healthcare system helps prevent overpopulation.

Private initiatives like the Bill & Melinda Gates Foundation offer a very promising approach. The support of such foundations provides companies with an incentive to work on drugs that would never be developed without funding. However, such patronage isn’t enough to solve the basic problem: the market-driven model of drug development as currently practiced is the best one I know – but it isn’t good enough.

We will all have to do a radical rethink: the aim of profit maximization will have to give way to that of “health maximization.” We would then develop drugs in a completely different way. There’s no lack of expert knowledge in companies and research institutes. My Max Planck research group alone is currently working on the development of five new vaccines, including vaccines for tropical diseases that still claim hundreds of thousands of lives each year. Basic research and applied academic biomedical research are stronger than ever in western industrialized nations.

At the same time, the pharmaceutical companies that (still) exist (still) have considerable experience in guiding new products through the test phases to the point of market readiness. Moreover, there is no lack of efforts to bridge the gap – which experts refer to as a “valley of death” – between academic research and industrial development. However, the successes remain limited because the market structures aren’t suitable. So the question arises as to what kinds of political tools could be used to set new and better incentives.

I’m not pushing for the control of drug development by a state body, but society must become more involved in drug development. Pharmaceutical companies must receive financial support to develop drugs for the treatment of smaller diseases. Perhaps we need financing models based on public funding bodies or state-guaranteed loans. In this case, however, the taxpayer must share not only the risk but also the profits.

It would appear that we have enough money to do this. The taxpayers’ money spent on saving a single bank would have been sufficient to develop ten or more new vaccines capable of saving the lives of hundreds of thousands of people. It would also have generated innovative impetus for the creation of many highly skilled jobs.

So how can the Max Planck Society contribute? It is our task to carry out cutting-edge work on the
level of basic research – and not to engage in a targeted quest for practical solutions to the plight of the pharmaceutical sector. Truly fundamental breakthroughs in the chemical, biological and medical sciences often involve completely new approaches to diagnostics, vaccines and drug treatments. While this kind of research doesn’t provide specialized, tailor-made solutions to specific problems, the scope of the fundamental progress it achieves is all the more extensive.

Knowledge of the possible applications and current challenges through active discourse with industry and the willingness to allow science to become an application often forces us out of our scientific comfort zone. A few approaches already exist for the further development of systematic results from basic research with a view to translating them into applications.

Further efforts are needed from both sides – both the Max Planck Society and the pharmaceutical sector – to ensure that we make the most of the discoveries as fair partners. Max Planck researchers aren’t a cheap “extended workbench” or a tax-funded source of ideas. Fair and effective ways must be found to organize the linking of knowledge and application in a way that ensures that society as a whole benefits, and not just a few individuals.

Basic research at the Max Planck institutes has yielded important products, also for the healthcare market. In far too many cases, however, that fact is virtually unknown. I would like to see a future in which Max Planck researchers devise new solutions and realize their essential features through greater problem awareness. In this way, we can offer society a return on its investment that goes far beyond the monetary value of the funding we receive.

The topic of new drugs must be put on society’s agenda. We must get used to the idea of ensuring the survival of our pharmaceutical sector, which merely gives the impression of being booming. And the pharmaceutical industry must get used to the idea that there are other values besides shareholder value.

Prof. Peter H. Seeberger was born in 1966. He studied chemistry at the University of Erlangen-Nürnberg and completed a doctorate in biochemistry at the University of Colorado. He has held the posts of Assistant Professor and Firmenich Associate Professor at the Massachusetts Institute of Technology in Cambridge, USA, and professor at ETH Zurich. He has been Director at the Max Planck Institute of Colloids and Interfaces and professor at the Freie Universität Berlin since 2009. Prof. Seeberger has published over 350 peer-reviewed articles, holds more than 30 patents, and has been awarded over 25 international prizes. Several spin-off companies have emerged from his laboratory. As a co-founder of the Tesfa-Ilg Hope for Africa Foundation, he supports the improvement of healthcare in Ethiopia.
Calculating with Carbon

Monitors and smartphones that can be rolled and folded up, solar cells in clothing and cheap chips in packaging that store details about products – these are just some of the applications that could become possible in the future thanks to molecular electronics. At the Max Planck Institute for Polymer Research in Mainz, Paul Blom and Dago de Leeuw are optimizing the organic substances for this type of technology, paving the way for affordable, flexible and printable electronic components.

Erudition has sparked many a scientific breakthrough, yet often enough, it also has a hand in helping a researcher find the field for which he or she was destined. In Paul Blom’s case, this helping hand came in the form of an unusual workplace convention on the part of his first employer after he had graduated from college: the Dutch electronics manufacturer Philips stipulated that the company’s researchers should work no more than six years in any given field. And so it happened that Blom one day found himself focusing on organic semiconductors, and no longer on inorganic materials, whose electronic properties he had been studying in the years prior to this switch.

“They wanted us to take on new fields of research with an open mind,” says Blom, who has been serving as Director at the Max Planck Institute for Polymer Research in Mainz for almost a year now. “But I think it had to do with the fact that scientists who are inexperienced in a particular field are easier to control,” he laughs.

Philips has since abandoned this practice. However, it was precisely this convention that set Paul Blom on his path 18 years ago – a path that he embarked on rather unencumbered by prior knowledge, but is now pursuing with great success. The goal of his research is to develop a technology with which to manufacture lightweight, flexible microchips, light-emitting diodes (LEDs) and solar cells on all kinds of materials using a sort of inkjet printer. Both scientists and companies in the field of electronics hope to use such technology to exploit new applications (see also MaxPlanckResearch 3/2011, page 26): monitors and computers that can be rolled and folded up, solar cells on tents and backpacks, and clothing with integrated sensors that record medical data and alert the wearer of impending health risks.
A stencil for solar cells: The researchers in Mainz are installing organic solar cells and LEDs on this substrate in order to metalize them as an electrode material. By using the respective template, they can identify the surfaces on which the metal has settled.
do through silicon et al., this field that Paul Blom was about to explore was essentially uncharted territory – and not just for the physicist. “So far, the development of materials for organic electronics is based mostly on trial and error,” he says. For a long time, the only things that chemists had to go on in their search for organic semiconductors were fairly vague clues. They lacked the detailed understanding of the mechanisms of charge transfer in organic electronic components that they needed in order to design the molecules for specific applications.

HOLES CAN TRAVEL FASTER THAN ELECTRONS

Paul Blom has already answered this question to a large extent with regard to organic LEDs and solar cells. “Some details remain unexplained, but we now have a very good understanding of how charge transfer works in these components,” says the Max Planck researcher.

During his time working at the University of Groningen and the Holst Centre in Eindhoven, he systematically investigated the factors on which the mobility of the charge carriers in organic substances depend. Charge carriers are, on the one hand, the negatively charged electrons that flow through conductors or semiconductors, and on the other hand, the positively charged holes that mobile electrons leave behind on an atom or a molecule. After all, these holes can also travel through a material – sometimes even faster than the electrons, as Paul Blom discovered.

Moreover, in LEDs and solar cells, the mobile electrons and holes are the actual charge carriers: in the former they create light, and in the latter they discharge as an electric current. The prerequisite in both cases is that the electrons are excited to make them mobile, so that the holes – which are then also mobile – are left behind. That is why LEDs and solar cells are made from semiconductors that fulfill this condition. Molecular electronics requires organic semiconductors, and semiconducting polymers have proven to be the material of choice.

In an LED, an electric voltage yanks the electrons out of their original environment; in a solar cell, this task is performed by sunlight. Inside the LED, the electrons must then quickly find a suitable hole, and then fall into this hole, releasing their excess energy in the form of light. In the solar cell, that is precisely what must not happen. Instead, the charge carriers must travel into the power grid as quickly and – more importantly – as numerously as possible.

This means that, in both components, the crucial factor is the mobility of the charge carriers – that is, the strength of the current that flows...
through the material (depending on an external voltage). In the semiconducting polymers, the holes are faster than the electrons, which is why they are responsible for most of the charge transfer. This is quite a heavy burden for them to bear: unlike the charges that zip through silicon, they virtually crawl through polymers, seeing as their mobility is one billion times lower. One thing that Paul Blom and his colleagues discovered is that, at least the higher the number of holes and electrons, the greater their mobility.

If the number of charge carriers is a decisive factor, then chemists must ensure that as many of them as possible can be created in a semiconducting polymer. Or that most of the current transporters present in a material don’t disappear in the wrong locations. That is precisely what happens all too often in organic semiconductors, due to the fact that an irregularity in a polymer chain becomes a trap into which the electrons disappear – a bit like a jogger falling into a gaping pit that suddenly opens up in front of him.

Since the faults in polymers throttle the flow of the charge, Paul Blom then decided to concentrate on analyzing these defects. “Our studies showed that the charge carriers in all conductive polymers get caught on the same type of defect,” the physicist says. “But we don’t yet know exactly what that defect is.” Possible candidates include hydrogen or oxygen molecules adhering to the chain molecules.

THE LOSS OF CHARGES CAN BE PREVENTED

Even though the exact location at which the charge carriers are lost still remains unknown, Paul Blom has some advice for chemists on how to prevent these disappearances. In order to understand how this trick works, it’s helpful to examine why defects become traps for the charge carriers: in semiconductors, only electrons that have been charged with energy transport a current. However, since everything in nature strives to achieve the lowest possible state of energy, the particles want to shed the excess energy as quickly as they can. The defects allow them to do just that. This is because they still have free spaces in their electronic order, and the conducting electrons fall into them, releasing excess energy.

Paul Blom wants to take away the electrons’ opportunity to rid themselves of excess energy, or rather, he wants to show others how this can be done: “With regard to organic LEDs, chemists must search for polymers in which the energy level of the conducting states is lower than that of the free states at the defects,” he says. The trap would then essentially hover above the electrons, and falling into such a trap is rather unlikely.

Preventing the charge carriers transporting the current from prematurely becoming lost at the defects is also imperative in the case of molecules for organic solar cells. After all, the aim is to harvest as many of them as possible in the form of an electric current using the photovoltaic elements. Therefore, the effectiveness of the elements, too, depends significantly on the type and distribution of the defects.

“If the movable charge carriers were created by light, they travel six nanometers on average before coming across a defect,” Blom explains. The charge carriers – the electrons and their corresponding holes – originate in long chain molecules when they are exposed to light with a sufficiently high...
level of energy. The electrons can flow out of the solar cell only by jumping onto a second substance that is used in organic solar cells. Using the analogy of a popular German tradition, these molecules can be compared to the lanterns that children typically carry during St. Martin’s Day processions: a buckyball hanging from the end of a rod-shaped molecule part. The structure of this buckyball composed of carbon pentagons and hexagons is reminiscent of the surface pattern of an old-style soccer ball.

**ELECTRONS DISAPPEAR AFTER SIX NANOMETERS**

“The electrons are available for generating a current only if they manage to find a buckyball before coming across a defect,” Paul Blom says. This means that the molecules that create mobile charge carriers using light, as well as the molecules that transport the current away, must be mixed inside a solar cell in such a way that the electron needs to travel significantly less than six nanometers before being received by a buckyball – otherwise it will probably disappear at a defect.

Blom and his colleagues at the Max Planck Institute in Mainz have now set themselves the task of identifying the chemical defect that causes the disappearance of the charge carriers needed for LEDs and solar cells to work. The necessary substances for this undertaking are supplied by the chemists working in the department headed by Klaus Müllen. The theoretical studies that help explain their measurement results are provided by Kurt Kremer and his fellow scientists.

But first, the researchers in Blom’s group will need specific types of laboratories in which to carry out their complex and meticulous studies. One such lab is a cleanroom in which they can produce the materials in a particle-free environment to eliminate the risk of accidentally introducing additional defects into the components and then not knowing exactly what they are measuring. The cleanroom is being constructed in a part of the building that was previously used by Blom’s predecessor and that has now been completely gutted. All that’s left is the bare brickwork of a space about as tall as a gymnasium and roughly the size of a tennis court.

Paul Blom walks quickly through the labyrinth of institute corridors to another laboratory. This is where technicians are currently installing three glove boxes, each having the dimensions of a sizable aquarium and being connected via airlocks. The researchers can reach into the airtight chamber with the full-length rubber gloves mounted on the front glass panel. Upon completion, they will use one of these chambers with a noble gas or nitrogen atmosphere to construct electronic components out of air-sensitive substances, and the other two chambers to characterize the properties of said components.

The instruments of choice for producing solar cells, LEDs and chips made from organic semiconductors are metalizers and spin coaters. The former create the contacts needed to combine the organic materials with the metallic world of modern-day electrics and electronics for research purposes. The latter very evenly distribute the solutions of the organic substances onto a spinning disk.

The real work horse in Blom’s group, however, is a voltmeter. The scientists use this instrument to characterize the physical properties of minute electric components and, in particular, to analyze the logistics of the electric charges within the structures. In a metal chamber roughly the size of a cake tin, the scientists bond their test components with needle-shaped electrodes attached to movable, jointed arms that are rather reminiscent of octopus tentacles. This allows them, for example, to measure the size of the electric current that
the test materials allow to pass through (depending on the voltage applied).

Voltmeters, spin coaters and metalizers can also be found in the laboratories in which some of Paul Blom’s colleagues have already begun working, because they don’t require the strict conditions that exist in a cleanroom. Dago de Leeuw is one of them. He headed the first project to be completed in the new department: the development of a non-volatile memory composed of organic ferroelectric material.

Non-volatile memories are the core components of every hard disk. They don’t forget their stored content when the computer is shut down, but there is a limit to how densely they can be packed, and they can’t be quickly reprogrammed. Volatile random-access memories, on the other hand, can be very densely packed and grant quick access when computer programs need data fast. Yet they store information only when connected to electricity.

**A SOPHISTICATED DESIGN FOR ORGANIC MEMORIES**

Ferroelectrics combine the best of both materials: they make data quickly accessible and can store information even without power. Just as the polarity of ferromagnets (to which modern non-volatile memories owe their good recollection) can be permanently reversed using a magnetic field, so ferroelectrics can also be switched back and forth between the zero and the one of a data bit using an electric field.

Materials scientists are currently studying numerous such materials (see MaxPlanckResearch 3/2011, page 34). Organic ferroelectrics stand out from this group because – just like organic semiconductors – their light weight and low cost makes them much more suitable for the production of versatile memories than is currently the case with inorganic materials. Silicon and the like can also be used to manufacture quick-access, non-volatile memories, but this still requires a complex procedure involving numerous individual steps.

In order to build non-volatile memories made from organic ferroelectric materials using a much simpler method, Dago de Leeuw and Paul Blom cre-
cross-talk in the memory. When the actual storage material channels a current up and down (a) between the tracks $B_1$, $B_2$, $W_1$, and $W_2$, a data point with a high resistance (red cylinder) can’t be read reliably – the test current will simply look for a new route via neighboring low resistances (green cylinders). With silver electrodes at the bottom and contacts made from aluminum and lithium fluoride at the top (b), the storage material becomes a diode: an electric one-way street. This technique prevents cross-talk.

The researchers placed the ferroelectric material with the embedded semiconductors between two thin electrodes: silver at the bottom and a mixture of aluminum and lithium fluoride at the top. The underlying concept is clever: charge carriers can enter the semiconductor only from the silver, not from the combination of aluminum and lithium fluoride. But they can flow into the latter. The semiconductors therefore act as diodes: electric one-way streets.

**ELECTRIC ONE-WAY STREETS LEAD TO THE DESTINATION**

How efficiently a current flows through the diodes depends on the polarity of the ferroelectric material coating the individual semiconductor canals. The ferroelectric material can be used to switch the resistance in the pores. And that’s precisely how the memory function works: a high resistance represents the one of a data bit, and a low resistance represents the zero, or vice versa. Since the polarity of the ferroelectric material is retained even in the absence of a current, the information isn’t lost, even when it isn’t constantly electrically refreshed. Moreover, a current that is too low to reverse the polarity of the ferroelectric material can easily be used to read the stored data.

But the only reason this concept works as well as it does is because Dago de Leeuw and Paul Blom devised the idea of the electric one-way street. “This arrangement prevents electric cross-talk – a problem prevalent in other memories that work with an electric resistance,” says de Leeuw. Due to this electric cross-talk, the bits with a high electric resistance can’t be read reliably.

The reason this problem has arisen is that modern-day, and even more so, future electronics are advancing into such minute dimensions that the contacts between the memory and the outside world must be arranged in such a way as to take up the smallest possible amount of space. The data bits in the more or less efficiently conducting canals are therefore written and read via two lattices of parallel tracks, between which lies a layer of the actual storage material. The tracks of the lower and upper lattice run perpendicular to one another and always cross paths at one of the current-carrying canals. Each memory canal can thus theoretically be activated with a voltage that is in contact with one lower and one upper track.

In practice, however, the response of a canal with a high resistance isn’t easy to detect when the upper and the lower lattice are made from a material like silver, which allows an electric current to flow along the canals in both directions. In that case, the current that the voltage is supposed to make flow through a high-resistance canal simply looks for a new path via neighboring canals with a lower resistance. But the current can’t take this detour unless it is able to flow to the top and the bottom through the canals. This is precisely the type of behavior that is thwarted by the “electric one-way street” memory concept developed by the team of scientists in Mainz.

“We were thus able to design a memory that is non-volatile, easy to read, and can be very densely packed,” says Dago de Leeuw. The only factor limiting the data density is the width of the tracks and the minimum distance between them. One single storage point requires barely more than 20 nanometers of space.

Paul Blom and Dago de Leeuw have now set themselves the task of simplifying the production of the memory material, and they aim to do so by implementing one of the fundamental principles of nanotechnology: self-assembly. Today, the semiconductor industry carves out transistors, diodes or
tracks from bulk material. This technique will grow increasingly difficult the smaller the structures become. The team of researchers in Mainz is therefore banking on the inherent tendency of many materials to adopt their own defined arrangement. The driving forces behind this phenomenon are the chemical and physical properties that cause the molecules to prefer certain configurations with respect to each other’s position.

Paul Blom and Dago de Leeuw have already benefited from molecular self-assembly to gather and group organic substances into transistors and diodes. Next, they aim to apply this same principle to the more sophisticated structure of the non-volatile memories made from organic semiconductors coated in ferroelectric material. And they are planning further applications as well: “If, in the future, we can create complex structures by means of molecular self-assembly, we will be able to substantially simplify the production of electronic components,” says Blom. Once this is achieved, if not sooner, organic electronics will be implemented on a large scale, facilitating applications that are currently uneconomical.

TO THE POINT

- Molecular electronics makes it possible to produce LEDs, solar cells and chips that are manufactured out of affordable, flexible materials and can be processed using a sort of inkjet printer.
- The mobility of electrons and the corresponding holes in organic semiconductors, and thus the efficiency of the resulting components, can be increased by using materials with an electronic structure that prevents the charge carriers from getting lost in defects.
- The thin layer of an organic ferroelectric material vertically traversed by semiconductor canals can be used to build non-volatile memories that can be densely packed and store data that can be written and read quickly and reliably.
- Electronic components just a few nanometers in size can be created from organic molecules using the principle of self-assembly, thanks to the molecules’ chemical and physical properties, which cause them to form organized structures by themselves.

GLOSSARY

Ferroelectric material: This term is based on an analogy with the ferromagnet. In a ferromagnet, magnetic moments can be aligned using a magnetic field, and they retain this polarity even outside of the magnetic field. In a ferroelectric material, an electric field shifts negative and positive charges against each other; they, too, retain their polarity even in the absence of the electric field.

Charge carrier: In metals and conductors in general, charge carriers are electrons that enable the transport of an electric current, for example. In metalloids, the electrons and holes are responsible for the current. Holes are created when electrons are excited, causing them to become mobile and then to begin to move. They leave behind a hole that can also move. When the electron falls back into a hole, energy is released in the form of electromagnetic radiation.

Molecular electronics: Made from organic materials, and therefore also known as organic electronics. Organic substances are composed of molecules that have carbon as their characteristic building block. These molecules can also occur as polymers, in which many structurally identical units combine to form chains or networks.
Isolated from the environment:
A new precision laboratory in Stuttgart houses an experimental cabin that optimally blocks out environmental noise, allowing Max Planck researchers to conduct extremely precise investigations into quantum phenomena in nanostructures.
Quantum World in a Cube

Nanoelectronics is at once a promise and a challenge. Within their tiny dimensions, electrons, the drivers of electronic circuits, exhibit some exotic quantum effects. Using ultrasensitive techniques, researchers in Klaus Kern’s department at the Max Planck Institute for Solid State Research in Stuttgart are studying the behavior of electrons in nanostructures.

People of antiquity were aware that you could impart an electric charge to amber, a fossilized resin, by rubbing it. The ancient Greek word for amber being elektron, when a particle with a negative elementary charge was discovered in the late 19th century, it was logical to call it an “electron”. We now know that electrons are what hold our world together. As quantum glue, they link atoms to form molecules and molecules to form the astonishing variety of the organic and inorganic world around us. The entire field of chemistry is based on the quantum properties of electrons. Without electrons as carriers of energy and information, society would face a total blackout.

It is thus no wonder that electrons remain a major focus of basic research. That is certainly true of Klaus Kern’s Nanoscale Science Department at the Max Planck Institute for Solid State Research in Stuttgart. The behavior of electrons in tiny nanostructures is a topic that pervades the department’s entire field of research. The research focuses on basic as well as exotic quantum properties that electrons exhibit in various environments.

Researchers are able to observe individual atoms

The scientists explore the peculiar properties of electrons confined within nanostructures by studying individual molecules as well as ultrathin layers like the carbon-based graphene, which could open up myriad new applications for electronic elements (see page 34, Chips from a Sheet). The researchers are able to shed light on the behavior of electrons in nanodimensions only because they are able to capture and study individual atoms and molecules. In doing so, they are constantly pushing the boundaries of what is technically feasible.

A single atom is so tiny that its size in relation to a chicken egg is like that of a chicken egg to the planet Earth. It’s just a few tenths of a nanometer (one billionth of a meter) in diameter.

TEXT ROLAND WENGENMAYR
“Nano” comes from the ancient Greek word for dwarf, and if you want to work with such dwarfs, you need the very finest tools – tools that can only be fashioned from atoms. Klaus Kern’s department uses tools that are essentially ultrafine metal needles, the tip of which can narrow in extreme cases to a single molecule or atom.

HARD BATTLE AGAINST A NOISY ENVIRONMENT

These ultrafine probes are used in scanning tunneling microscopes, instruments that can actually render individual atoms visible. The probes move across a surface, scanning individual atoms as they do so. Information about atomic structure is provided by electrons that manage to cross the vacuum barrier between atoms on the sample surface and atoms on the probe tip. Physicists say that the negative charge carriers “tunnel” through the vacuum zone, which would normally pose an impenetrable barrier.

But capturing individual atoms with supersharp needles means waging a hard battle against an environment full of noise. People who live in old buildings and play vinyl records will be familiar with the problem in a crude form. As you walk over the springy wooden floorboards, the needle hops across the record grooves. The needle of a scanning tunneling microscope reacts to tiny vibrations in the same way, but far more sensitively. An experiment can even be ruined by the public bus that stops a hundred meters away in front of the institute.

Research on two levels: Technician Wolfgang Stiepany adjusts an aperture in a scanning tunneling microscope whose outer vacuum jacket extends through a hole in the ceiling into the floor above. Numerous pumps, compressors and electronic controllers create the necessary conditions for the precision experiments inside the instrument.
The scientists in Stuttgart thus have to take great pains to shield their experiments from the outside world. The work of Christian Ast and Markus Etzkorn demonstrates what that means in practice. The two physicists use a highly sophisticated scanning tunneling microscope. Ast and his team started planning and constructing their experiment in 2003, but it wasn’t until early 2011, after a scientific marathon full of technical hurdles, that they achieved success. For example, a circular hole had to be hewn into the concrete ceiling of the laboratory for the huge steel column of the outer vacuum jacket to pass through. The instrument, whose inner mechanisms are constructed like a high-tech onion, occupies two floors of the building.

At the core of the instrument, behind multiple layers of cooling jackets and shields, lies the actual scanning tunneling microscope. “The scanning head is about the size of a fist,” Ast explains. Samples are introduced into the innermost chamber of the instrument, which is nearly the only one of its kind in the world, through an elaborate series of airlocks. Since January 2011, the cold maintained inside the instrument is so extreme that even a Siberian winter is hot by comparison. The researchers have come within a few thousandths of a degree of absolute zero, minus 273.15 degrees Celsius. Thermal energy being nothing more than the chaotic motion of atoms and electrons, which would wreak havoc with the experiment, heat must be almost completely banished from the instrument.

The instrument does more than just provide ultrasharp images. At these low temperatures, many metals become superconductors – in other words, they lose their electrical resistance. Superconductivity is a collective quantum phenomenon that binds electrons together in a sort of mass wedding. Electrons form couples, known as Cooper pairs, which then sweep, without dissipation, through the material in a kind of quantum ballet. Despite having been discovered over a century ago, this complex choreography of electrons still poses many unanswered questions.

SUPERCONDUCTIVITY SURVIVES A STRONG MAGNETIC FIELD

One of the questions the Stuttgart-based researchers asked themselves was how superconductivity behaves when it is confined within the tip of a scanning tunneling microscope. To find out, Ast’s team used an extremely powerful electromagnet, which is also housed within the onion layers of their instrument. In superconductors, as in a perfect dynamo, magnetic fields generate circular countercurrents. These eddies try to squeeze the magnetic field out of the superconductor. However, if the magnetic field is too strong, superconductivity collapses. “To put it simply, the compensation currents become too strong,” Ast explains. They tear the Cooper pairs apart, so to speak.

As early as 1970, physicists wondered what would happen if superconductivity were constricted too tightly for the eddies to destroy it. They predicted that a strong magnetic field would then pen-
etrate through the superconductor without separating the Cooper pairs. Later experiments actually confirmed this predicted longer lifespan in ultrathin superconducting films. Thanks to Ast’s team, we now know that the phenomenon also applies to superconducting tips of scanning tunneling microscopes – knowledge that is important not least for the continued use of superconducting probe tips in experiments today.

**EXPERIMENTS FLOATING ON AIR SPRINGS**

“We will be able to reduce the noise even more when we move into the new precision laboratory,” says Christian Ast, with an eye to the future. The architecturally interesting laboratory building, which was inaugurated in 2012, provides an ideally shielded environment for the experiment. The setup is installed in one of eleven house-size cubes within a large hall. To aid identification, each cube is painted a different color, which inadvertently makes the arrangement look like the colorful building blocks of a giant child.

On the upper floor, which floats on air springs, each cube contains a supersensitive experiment. The lower floor, which is almost perfectly isolated from the floor above, houses the necessary infrastructure comprising vibrating vacuum pumps and other interfering equipment. In addition to vibration protection, the cubes are also fitted with sophisticated shielding against electromagnetic radiation, which is ubiquitous in the environment. Once closed, safe-like doors shut out all interference.

One cube contains the scanning tunneling microscope used by Uta Schlickum. “We can pick up a single molecule with our needles or, for example, place a metal atom at a specific location within a molecule, explains the physicist, who heads an Emmy Noether junior research group. Schlickum’s tool
is a probe tip that culminates in a single metal atom. Using this quantum probe, her team is investigating how electrons flow through a molecule as tiny quantum currents.

For the experiment, a molecule is placed on a nearly perfect copper surface. Copper makes a particularly good substrate because it is an excellent electrical conductor and at the same time isn’t chemically aggressive. The latter is important, because the team wants to find out how minor chemical changes to the molecule affect its electrical properties.

“These relationships differ from molecule to molecule,” the physicist explains. Recently, the researchers placed pentacene under the probe tip. This molecule is a good organic semiconductor and is therefore a hot candidate as a material for future organic electronics. However, what exactly happens in molecules when electrons flow remains a mystery. Nor is it known how a molecule’s properties are altered by chemically attaching metal atoms or smaller molecular building blocks to it.

A SOLAR CELL THAT CHEMICALLY BREAKS DOWN WATER

The five hexagonal rings of pentacene contain 22 carbon atoms and 14 hydrogen atoms. The correspondingly large number of electrons hampers a precise understanding of the molecule’s electronic properties. This is because the behavior of the electrons depends on the quantum states of the molecule, and the more electrons that are involved, the more complex the quantum states become.

The shapes these states take are reminiscent of the long extinct trilobites. Such quantum curves are attractive not only to basic researchers, but to anyone who wants to use these molecules in organic electronics in the future. Organic electronics could facilitate environmentally friendly manufacturing of clothing and packaging equipped with flexible and cheap electronic circuits, light emitting diodes or solar cells.

Future solar cells of a very special kind are a pet project of Soon Jung. The Korean draws two lines and an arrow between them: that’s how high sunlight has to make electrons hop up an energy quantum ladder. “We need around 1.4 volts,” she says. That’s because the solar cells the Korean is researching aren’t meant to produce electrical current; lower voltages would be sufficient for that. Instead, the photovoltaic element is designed to split water chemically into hydrogen and oxygen in a highly efficient manner. If hydrogen could be generated on a large scale in this way, it could provide a means of chemically storing renewable energy that would be superior to today’s best electrical batteries. After being distributed through a network of pipelines, the hydrogen generated could be used to power fuel cell cars.

For this process to work, every electron in the solar cell that is liberated by sunlight must contribute energy to permit the 1.4 “electron volt” jump. In the molecular world, that’s quite a leap. Moreover, the solar cell should make as efficient use as possible of the full spectrum of sunlight. Jung’s group is thus studying promising molecular candidates in the hope that light quanta impinging on them will efficiently release electrons with the desired energy. The chemist points out that this is still firmly in the realm of basic research.

A SINGLE PHOTON AT THE PRESS OF A BUTTON

In another cube, Klaus Kuhnke, together with his Ph.D. student Christoph Grosse, is approaching the matter from the opposite direction. The two researchers hope to generate light with electrons – but not just any light. It has been known for some time that the fine needle of a scanning tunneling microscope, together with the smooth metal surface below it, forms a kind of cavity – or at least it has the appearance of a cavity for tunneling electrons.

If the experiment is set up correctly, an electromagnetic wave is generated. It behaves like a vibrating string above a soundboard, explains team leader Kuhnke. The result is a weak light, but one with special properties. Practically any light source produces light quanta, known as photons. The photons are produced randomly, similar to the way in which radioactive nuclei decay. But physicists want to be able to generate one and only one photon whenever they desire – at the press of a button, as it were.

“It’s called photon on demand,” says Kuhnke, and in recent years, it has been demonstrated by physicists in so-
phisticated laser experiments. The Stuttgart-based scientist hopes to be able to develop an alternative “quantum lamp,” a light source that would be useful in basic quantum experiments. “You could also use it to test the security of transmission lines,” the physicist explains, putting the phenomenon in a contemporary context. “If a photon we know has been sent fails to arrive at its destination, we can conclude that there’s an eavesdropper on the line.”

In information technology, electrons are interesting not only as a light source, but also as carriers of spin. Spin, to use a visual analogy, corresponds to the axis about which an electron rotates, transforming the charge carrier into a tiny elemental magnet. So it could also be visualized as a small magnetic needle. The spin enables a single electron to carry two bits of digital information. One bit is conveyed by the charge of the electron, as in conventional electronics, and another bit by the orientation of the particle’s spin—that is, the direction of the magnetic needle.

This idea has given rise to the research field of spintronics, which promises faster and more energy-efficient electronics. The trail in Stuttgart leads to Marko Burghard. The physical chemist and his group are working on two types of materials that are attracting a great deal of attention within the research community: graphene and topological insulators. These materials all share the characteristic of having a superflat two-dimensional electron system.

**FUNCTIONALIZATION TRANSFORMS GRAPHENE INTO A MAGNET**

Graphene consists of a single layer of hexagonal carbon honeycombs. Until a few years ago, it was unclear whether such a material could actually exist in a stable state. Graphene flakes, after all, are just one atom thick in one dimension, but macroscopically large in the other two dimensions. Surprisingly, graphene has proved to be highly stable and extremely resistant to tearing.

Burghard is particularly interested in the material’s electronic properties. In principle, the spin of the electrons flowing in graphene can be directly manipulated. However, to make functioning spintronic components from graphene, it is necessary to chemically attach various molecules to it. This “functionalization” clears the way for building in various switch elements on a graphene substrate. But attaching molecules to the carbon layer is no mean feat: “The problem is precisely the high chemical stability of graphene,” says Burghard. Despite this, his group, working in international cooperation, recently demonstrated that it is possible to construct a proper magnet—ferromagnet—after suitably functionalizing graphene.

Burghard is even more fascinated by topological insulators than by graphene. These compounds owe their curious name to the fact that they don’t conduct any electrical current in their interior—in the third dimension. Yet they are good electrical conductors across their two-dimensional surfaces.

A simple picture helps illustrate the remarkable behavior of these materials. In conductors and semiconductors, electrons in the outermost shells...
of atoms are responsible for the materials’ electrical conductivity, because they are able to break free and travel through the material. In topological insulators, in contrast, the electrons are held captive in atomic orbitals. However, at the surface of the material, the orbitals are truncated, allowing electrons to break free and move about unhindered. An electrical current in this two-dimensional “electron gas” is associated with an electron spin orientation. It is this that makes topological insulators so interesting for future spintronic applications.

The first synthetic topological insulator was demonstrated in 2008. The scientists in Stuttgart even recently discovered that nature itself produces such materials. They found that the natural mineral kawazulite is a topological insulator. “Our sample comes from an old gold mine in the Czech Republic,” says Burghard. The researchers were electrified not only by the fact that the mineral occurs naturally; they also found that kawazulite is a perfect topological insulator in the laboratory, despite being full of natural impurities. This shows that the effect is extraordinarily stable.

If you peer over the shoulders of the researchers in Klaus Kern’s department, you will learn about the many approaches they are taking to investigate the electronic properties of nanostructures. You will also quickly realize that electrons act radically differently on the nanoscale than on the macroscale, and that they are full of surprises. In particular, the Stuttgart-based researchers aim to expand our knowledge of the often bizarre quantum properties of the nanoworld. But like all good basic research, nanoelectronics has the potential to revolutionize technology in unforeseen ways. Spintronics, organic electronic components and solar cells for sustainable energy supply are just a few of the many conceivable applications.

TO THE POINT

- Electrons exhibit different properties in nanostructures than they do on the macroscale, and sometimes exotic quantum effects also occur.
- To investigate the electronic properties of individual atoms and molecules, researchers at the Max Planck Institute for Solid State Research use scanning tunneling microscopes that are meticulously shielded from any interference such as vibrations and heat and that are among the best in the world.
- The quantum effects that occur in nanodimensions could lead to the development of spintronics or single-photon light sources. Thus, they clear the way for new approaches in information processing.
Material scientists are pinning their hopes for the electronics of the future on graphene more than almost any other substance. The teams working with Klaus Müllen, Director at the Max Planck Institute for Polymer Research in Mainz, and Jurgen Smet, group leader at the Max Planck Institute for Solid State Research in Stuttgart, are striving to make these hopes a reality.
Compared with modern scientists, Stone Age people had an easy life. Though they had to be skilled at making tools such as hand-axes, axes or arrowheads for various purposes, they found the stone they used for them in their natural environment. Today, in contrast, scientists often have to first develop the material before they can construct devices with different functions. “We need material innovation,” says Klaus Müller from the Max Planck Institute for Polymer Research in Mainz, whose work is dedicated to the carbon material graphene.

It could be argued that Müller and his team in Mainz found the material of their research dreams long ago – a material that some in the media like to call a miracle material because of its unique mechanical, electrical and thermal properties that promise to provide a whole potpourri of new applications. Not all graphene is the same, however – its properties depend very much on its form, on the other substances it is in contact with, and on the ambient conditions to which it is exposed.

The network of carbon atoms arranged in a honeycomb pattern and having a thickness of just one atomic layer is more a material platform than a material – a playground for researchers, a versatile superhero of a material that develops different strengths depending on its particular manifestation.

The chemist Müller and his team in Mainz, and the physicist Jurgen Smet at the Max Planck Institute for Solid State Research in Stuttgart, are therefore looking for new forms of carbon sheets for innovative graphene designs that enable functions that the simplest form of graphene – the uniform two-dimensional carbon film – doesn’t.

The researchers are fascinated by the exotic nature of graphene: electrons...
move more quickly and collision-free in it than in any other material; it conducts heat better than diamond – long the unsurpassed champion here; and its tensile strength would make it possible for a suspension bridge to span the ocean from Ireland to the Azores – from a purely mathematical point of view, of course. “It is such wonderful physics,” says Jurgen Smet, whose eyes sparkle as he describes one of his research projects on graphene.

Intertwined with their basic research is the prospect of the subsequent industrial mass production of their material innovations, be it for more powerful nanoelectronics, for rechargeable batteries with a longer life and extremely high capacity, or for superconductors that conduct electricity without loss.

The carbon sheets are a natural choice for nanoelectronics applications because electrons race through the material at very high speeds, and because the sheets are extremely thin. Thanks to the nimble charge carriers, electronic components based on graphene could compute faster and thus make it possible to build more powerful computer chips than can be achieved with current silicon technology.

IN NARROW RIBBONS, GRAPHENE BECOMES A SEMICONDUCTOR

Some digital circuit components could also be produced on a significantly smaller scale from the inconceivably thin graphene than from silicon. This would further increase the power of computer chips. In addition, the flat material offers scientists the opportunity to construct three-dimensional digital circuits, allowing several times the computing power to be accommodated on a given chip area.

There is a drawback, however: digital circuits require components that can be switched to and fro between two states – “on” and “off” – so-called transistors. This requires semiconductor materials like the silicon used in today’s computer chips. Yet pure, two-dimensional graphene isn’t a semiconductor, but a semimetal.

The two classes of materials differ in their band gap – a semiconductor has one, while a semimetal like graphene does not. The band gap separates the so-called valence band, in which electrons remain immobile, and the conduction band, in which the charge carriers race through a material and can thus contribute to the electrical conductivity.

To overcome the band gap, electrons need a shot of energy. In a semiconductor, the energy difference between the two bands is large enough for the material to be switched from conducting to non-conducting by applying a voltage. It is therefore suitable as a transistor in a digital circuit.

But graphene wouldn’t be graphene if it couldn’t acquire a band gap as a re-
The result is that a band gap is generated – an energy range in which the electrons can’t exist. The narrower the ribbon, the larger its band gap. Whether there is a band gap at all and how large it is depends also on the form of the ribbon edges.

This complexity, in Müllen’s opinion, makes the production of graphene nanoribbons a task for chemists. Why? Physicists produce the ribbons in different ways. They sort of cut out ribbons of graphene with electron beams. Or they slit open carbon nanotubes, practically tubular graphene, and unroll them – just like making tagliatelle from macaroni.

THE FORM OF THE EDGES AFFECTS THE PROPERTIES

“But these methods don’t give us any control over what the edges look like,” says Müllen. It’s very important to be able to produce custom-made edges, because irregular edges slow down the electrons. This means one of graphene’s major advantages – the speed of its electrons – is lost. But even when the edges are regular, this shape influences the electronic properties.

At the edges of the carbon ribbons, the carbon hexagons that make up graphene can, for example, be offset from one another. This produces adjacent bays resembling armchairs at the edge. Or the edge takes the form of a zigzag. The armchair version leads to a band gap, while the zigzag version doesn’t necessarily. Instead, the zigzag version has at its edge electrons with a specific spin – a magnetic property that makes the particles resemble the needles in a compass. This makes these types of nanoribbons interesting for a new form of electronics – spintronics – which aims to store and process bits, not with the electronic charge as previously, but with the spin.

The researchers in Mainz can control the form of the ribbons and thus also the form of the edges down to the level of individual atoms. They can guarantee, for example, that the armchair version is formed because they plan where each individual carbon atom will sit in the finished GNR. They achieve this by taking more or less the opposite path of the one the physicists use. Instead of cutting up a large sheet of carbon, they build up the ribbon from smaller hydrocarbon molecules. So they work more like bricklayers, constructing a building according to a plan, brick by brick, rather than like sculptors, removing material from a workpiece with a chisel.

With the bottom-up method, they come very close to the highest art of nanotechnology, the construction of materials atom by atom – just as Eric Drexler, the pioneer of nanotechnology, forecast in the 1980s. Since this method allows the scientists to control the structure of the product as precisely as possible, they can also control its physical and chemical properties right down to the fine details.

This allows nanoelectronic components to be designed in a specific way, something sculpting methods couldn’t do, because even the most delicate chisels the semiconductor industry uses to chisel transistors out of silicon, for example, are too coarse to work on structures down to the level of individual atoms with precision.

In order to build up the carbon nanoribbons using the bottom-up method, the Mainz researchers use molecules...
composed of several hexagonal hydrocarbon rings. At two of their ends, these monomers bear a different atom, for example bromine instead of a hydrogen atom. When the chemists heat the monomers on a metal surface such as gold to 200 degrees Celsius, the placeholder atoms separate off, leaving behind reactive coupling sites on which the monomers link up to form a chain. Since the hydrogen atoms at the ends of the chain-linked monomers get in each other’s way, the chain is initially wavy. The researchers remove these interfering hydrogen atoms by heating the intermediate product to around 400 degrees Celsius. The benzene rings of neighboring monomers now combine to form a continuous nanoribbon. The Mainz-based researchers have developed a similar method to produce ribbons in solution as well. This is more practical for large-scale technical applications.

Aside from the control over the edges, the method provides some further adjustment options that allow very different carbon nanoribbons to be designed. In the future, these could play very different roles in nanoelectronics. “By choosing the monomers, we can control the ratio of length to width of the GNR,” says Müllen’s colleague Xinliang Feng.

METHODS SUITABLE FOR MASS PRODUCTION

If the chemists mix in monomers with three placeholders among the molecules with two bromine atoms, Y-shaped ribbons form that can be used in circuits for branching lines. Working in collaboration with researchers at the Swiss Federal Laboratories for Materials Testing and Research in Dübendorf, the scientists in Mainz have even produced GNR linkages with band gaps of different widths. Such heterostructures also play a role in conventional microelectronics and could thus be translated into a new type of nanoelectronics.

Suitably shaped GNRs could also be used in solar cells, because they absorb visible and infrared light, as Müllen’s team found out using theoretical computations carried out in collaboration with Belgian and French researchers and BASF.

Müllen’s team has been carrying out research with the Ludwigshafen-based chemicals group since 2012 in a joint research lab established especially for the purpose. “What we are doing is basic research, but we are open to application possibilities,” says Müllen. This is more than just lip service, given that the production methods developed in Mainz are, in principle, suitable for mass production. For one thing, the monomers are easier to handle as the starting material than graphene. Moreover, both of the chemists’ production methods have advantages for industrial manufacturing.

The method of producing the carbon nanoribbons in solution is simple
Perfectly clean: Wafa Rouabeh, Patrick Herlinger and Jurgen Smet use an oven to deposit carbon onto metal surfaces so that it forms graphene.

In order to arrive at meaningful and reproducible results, the researchers investigate the material in the cleanroom. The suits prevent dust particles from detaching from their clothing.

and low cost. Furthermore, it also offers the possibility to produce electronic circuits using rapid, low-cost printing methods. The other method – depositing graphene on surfaces – needs only relatively low temperatures and is thus compatible with current manufacturing methods in the computer industry.

Metals, however, aren’t suitable as graphene substrates in electronics because they would short-circuit the component. This is where physicist Jurgen Smet comes into play. One of his graphene projects aims to develop a transfer process. The Stuttgart-based researchers are using various methods in an attempt to transfer graphene from copper substrates to other surfaces.

Although Smet has a passion for basic research, he also has an eye to the eventual industrial production. “We develop methods where the substrate isn’t dissolved, in order to prevent the copper from being lost in the process.” The researchers use a stamp, for example, that lifts the graphene from the substrate and deposits it onto a different one. “Here, it’s important to apply a specified pressure in a way that is reproducible,” emphasizes Smet.

THE MATERIAL IS UNCHARTED TERRITORY

The researcher hopes to achieve this goal in collaboration with the neighboring Fraunhofer Institute for Manufacturing Engineering and Automation. He and his team are trying out different ways to make it possible to use a graphene-coated copper foil as, for instance, the electrode in a galvanic cell. For this, they have versions in which the copper is decomposed only slightly or not at all.

Apart from searching for practical transfer methods, Smet is also working on much more fundamental aspects of graphene. He views the material as an uncharted territory that holds many surprises in store. “It combines an unusual number of superlatives,” he says, explaining the fascination that graphene triggers in researchers, resulting in a veritable army of scientists around the world investigating the material. The hype has the disadvantage that “the low-hanging fruits have long since been harvested,” as Smet puts it. Research is thus delving into more and more detail.

Jurgen Smet would like to make inroads into the uncharted territory of graphene research, as it were, and discover new properties of the material in the process. To this end, he puts flat graphene in different environments, combining it into double layers, for example, wetting it with thin liquid layers, or embedding it between other materials. Applications lie in store here that could be important above and beyond computer electronics – for instance in energy storage or superconductivity, which promises loss-free transmission of electricity.

At the root of all this is the physicist's curiosity. “Graphene is ideal for investigating the interaction between the electrons in it,” says Smet. Phenom-
ena such as superconductivity, for example, or so-called Bose-Einstein condensates, are based on such interactions. Physicists around the globe study these macroscopic quantum objects in order to explore what the exotic states of matter have to offer.

The first step in these investigations is to bring large numbers of additional electrons into the graphene so that they interact with each other. “We want to find out how much the electron density in the graphene can be increased,” says Jurgen Smet. There is a possibility that this can be done to such an extent that graphene becomes a material that can be converted into a superconductor at the push of a button.

The physicists produce the starting material for the experiments themselves: sheets of perfect graphene, as large as possible, featuring a perfectly regular honeycomb lattice. In a reactor, they pass methane vapor over a copper foil on which graphene forms in a chemical reaction.

The researchers then dope the carbon sheets with electrons in different ways. One rather simple way to charge the material with electrons involves coating graphene with an electrolyte: a liquid that contains lithium ions. The lithium ions attach themselves to the graphene, so their positive electric charge has to be compensated. Electrons thus migrate from metal contacts into the graphene.

**GRAPHENE SUPERCAPACITORS AS ENERGY STORAGE DEVICES**

“The separation between the ions and the electrons in the graphene is only one nanometer,” says Smet. The narrow separation between positive and negative charges transforms the graphene wetted with the electrolyte into a capacitor with an extremely high capacity, a supercap. “This means that a very high charge carrier density can be achieved with a small voltage,” explains Smet.

These supercapacitors are interesting not only for the study of interactions between densely packed electrons, but also for applications as energy storage devices. This is because a capacitor can store more energy the denser the charge carriers in it are packed. The Max Planck researchers in Stuttgart are currently trying to develop a production method – one that is also suitable for industrial purposes – for coating the graphene with an electrolyte that is as viscous as possible.

Smet’s team is taking another dip into graphene’s bag of surprises by combining the substance with another two-dimensional material. This material is boron nitride, which forms a flat honeycomb lattice just like graphene, but whose hexagons consist of equal proportions of boron and nitrogen atoms. Unlike graphene, boron nitride is an insulator.

The physicists produce a sandwich by packing two layers of graphene between three layers of boron nitride. This produces two very close but electrically insulated graphene layers. They sort of talk to each other: electrons in one layer interact with atoms in the other layer that are missing an electron – physicists call them holes. Electrons and holes form a species of particle that is new for graphene: excitons, which resemble hydrogen atoms.
In contrast to electrons and holes as such, excitons belong to the family of quantum mechanical particles known as bosons. These, in turn, can combine in a solid to form a kind of superparticle, a Bose-Einstein condensate. This exotic state of matter normally occurs only at a temperature just above absolute zero, at minus 273 degrees Celsius.

“A hotly disputed theory predicts that, in such a system, a Bose-Einstein condensate could also exist at room temperature,” says Smet. Only empirical research could put an end to the controversy, making it a challenge for physicists like him. “The material made of graphene and boron nitride provides us with many options to tweak the properties to achieve this objective,” says Jurgen Smet. For example, the density of the excitons can be set to a specific value.

Bose-Einstein condensates at room temperature would be interesting not only for those working in basic research. Some physicists are of the opinion that it would also be possible to use them for quantum computers. This type of computer, which is still very much in its infancy, could solve certain tasks in no time that would take conventional computers an eternity.

Whether as a pure material or a component of new material combinations – the incredibly versatile graphene will likely create quite a stir yet. Max Planck researchers can provide crucial impetus for this. Thanks not least to their skills in constructing new materials at the atomic level, they are teasing more and more new functions out of the simply constructed carbon compounds. “Material innovation,” as Klaus Müllen puts it.

So, at some time in the future, we could have the situation where hardly any electronic device will be conceivable without graphene’s family of materials. Graphene – as well as other technologically interesting carbon compounds, such as carbon nanotubes and fullerenes, which are shaped like soccer balls – could possibly contribute to a new age, the Carbon Age, where the element might play a similarly indispensable role as stone did in the Stone Age, or silicon in the Silicon Era.
We Understand that We Don’t Understand

The words used to express problems in understanding are similar in many languages.

The expression “huh?” is perhaps not the politest way of telling someone you don’t understand, but it’s an indispensable instrument of human communication. Without it, conversation would falter as communication breaks down. Researchers at the Max Planck Institute for Psycholinguistics in Nijmegen in the Netherlands analyzed various languages from across the world and discovered that, in each of the languages they studied, there is a word more or less identical in sound and function to “huh?”.

We Understand that We Don’t Understand

The words used to express problems in understanding are similar in many languages.

Expressions such as “huh?”, indicating a lack of understanding, can be found in comparable forms in a variety of languages.

Light Observed in Transit

An atom in a resonator registers a photon without destroying it.

Seeing light is trivial enough; seeing light in transit, however, is anything but trivial. Physicists working with Stephan Ritter and Gerhard Rempe at the Max Planck Institute of Quantum Optics in Garching managed to do just that. Our eyes are able to perceive a beam of light in the mist or a laser fired into the air only because the particles of light, called photons, are scattered and impinge on our retinas. But then these photons are gone. The ability to register a photon in transit is a helpful aid to quantum information technology, which uses the quantum characteristics of particles to increase the security with which information is transferred and the speed at which data is processed. To this end, the researchers in Garching caused a photon to interact with an atom that fixes a laser in a resonator comprised of two mirrors. They put the atom in a state whose phase can be shifted by a photon. If one imagines the atom as a clock, the phase is the angle between the hands. The photon passing by resets the clock, as it were, without altering its own characteristics or being lost. The physicists can then quite easily measure the phase shift with a laser. (Science Express, November 14, 2013)

Light flying past us is beyond our perception. We perceive only those photons that are scattered and deflected toward our eyes by dust, mist or molecules in the air. Observing these particles of light extinguishes them. Now Max Planck researchers have detected a light particle that subsequently continued on its flight path.
Gas Station in Space

Astronomers observe how primordial gas flows into a galaxy

Even galaxies need to fill up their fuel tanks. After all, especially at the beginning of their lives, huge numbers of new stars are created within them – and that requires the necessary substance. So when galaxies like our Milky Way were formed some ten billion years ago, they evidently drew in large quantities of cosmic matter from vast reservoirs of hydrogen. Since the dawn of the universe, this hydrogen has been present in the wilds of intergalactic space. But how does the matter find its way in to the Milky Way? Supercomputer simulations depict cold flows of gaseous matter flowing into the galaxy. To test this scenario, researchers – including some from the Max Planck Institute for Astronomy – focused on a galaxy whose light takes 11 billion years to reach us. And indeed, they found inflows of gas that show traces of heavy hydrogen, proving that it really is primordial matter. (Astrophysical Journal Letters, October 20, 2013)

Music from the Rain Forest

The song of the musician wren sounds like human music

Cyphorhinus arada is more commonly known in English as the musician wren. And with good reason, as composer and musicologist Emily Doolittle and biologist Henrik Brumm of the Max Planck Institute for Ornithology in Seewiesen discovered. This small brown bird, a denizen of the Amazon rainforest, sings perfect consonances such as octaves, fifths and fourths. As a result, it sounds very much like human music. Listening to the bird’s song, the scientists found passages that bear a striking resemblance to motifs used by, for instance, Bach and Haydn in their compositions. However, the musician wren doesn’t sing in a specific key, as a human singer would. Yet its preference for perfect intervals gives the impression that the sounds follow a musical scale. Its song makes the musician wren an exception among the 4,000 or so different species of song birds, since bird song isn’t normally structured in the same way as human music. The researchers don’t yet know why the musician wren sings as it does, or how it perceives its own song. (Journal of Interdisciplinary Music Studies, October 15, 2013)

The Geometry of Cancer Cells

Malignant cells could be identified more rapidly using characteristic fractal samples

Time is a decisive factor in the fight against cancer. If suitable treatment is to be initiated with greater speed, it is essential for the tumor to be characterized quickly. A new approach pursued by scientists working with Joachim Spatz, Director at the Max Planck Institute for Intelligent Systems in Stuttgart, could substantially accelerate the diagnosis. The researchers are using the fractal geometry of the cell border to identify tumor cells. Fractal structures on a small scale exhibit the same features as on a large scale. As the scientists have since discovered, the statistical distribution of irregularities in the cell border differs from one type of tumor to another. As a result, the cells can be identified at a glance through a particularly high-contrast microscope. Previously, a time-consuming immunohistological examination was required, which involved staining the cells different colors in several stages. (Nano Letters, September 30, 2013)

The more frayed, the more malignant: A tumor cell can be distinguished by its fractal geometry, or more precisely, its degree of fractality. The cell on the right displays a greater degree of fractality than that on the left, indicating that it is more aggressive.
Lonely in Space

Newly discovered planets without a host sun help us understand the origins of stars

Heavenly bodies with no host sun floating freely in space and with a mass similar to that of a planet can originate in the same way as stars, as researchers at the Max Planck Institute for Astronomy discovered. They investigated a variety of subjects, one of which can practically be considered a newborn, having originated just two million years ago. And just like a young star, OTS 44, as this lonely planet is called, is surrounded by a disk of gas and dust. What’s more, its birth isn’t yet complete: the astronomers found signs that OTS 44 is still drawing in matter from the surrounding disk and increasing in mass. The disk comprises at least 30 times the mass of the Earth and is regarded, like the incident matter, as a clear indication of a mechanism of origin that is typical of the birth of stars. They therefore concluded that the same processes that apply to stars also apply to individual objects with the mass of a planet.

(Astrophysical Journal Letters, October 9, 2013)

Bacteria and Rare Earths

Methane-decomposing microbes in hot springs need these valuable metals to produce energy

They are called rare earths, but they aren’t really that rare: the 17 metals belonging to this group are fairly evenly distributed within the Earth’s crust, with the result that there are only a few locations where extracting them is worthwhile. Without these metals, mobile phones, screens and computers wouldn’t work. And it seems that some life forms can’t do without them, either. In a hot volcanic spring, a team of researchers including scientists from the Max Planck Institute for Medical Research in Heidelberg are the first to have discovered a bacterium that needs rare earth metals to live. However, genome and proteome analyses lead scientists to suspect that the new enzyme variant is widespread, particularly among bacteria in coastal waters.

(Environmental Microbiology, October 2013)

The methanol dehydrogenase of the bacterium Methylacidiphilum fumaroliicum uses the rare earth metal cerium (Ce) instead of calcium as a cofactor.
The World’s Smallest Memory

Controlling the magnetic moment of individual atoms opens up new possibilities for compact data memories

One bit per atom: A team including Arthur Ernst and other researchers at the Max Planck Institute of Microstructure Physics in Halle succeeded in storing information in such a small space. The scientists fixed a single holmium atom on a platinum surface and were able to prove that the spin of an electron on the rare earth atom remained stable for more than ten minutes. The spin can be imagined as the direction of rotation of the electron, to which it imparts a magnetic moment that can be oriented in two directions in an external magnetic field. Until now, the spin of an individual atom hasn’t retained its orientation for more than a millionth of a second, with the result that, at present, a cluster of several million atoms is required to ensure that one magnetic bit remains safely stored on a hard disk over a long period. This current work represents a major step toward the goal of storing data permanently in individual atoms. (Nature, November 14, 2013)

Individual atoms can store data: This image taken by a scanning tunneling microscope shows holmium atoms on a platinum surface. In this quantum system, the spins, and thus the magnetic moments of individual holmium electrons, remain stable for more than ten minutes.

Pit of Bones

Max Planck researchers decode the oldest mitochondrial DNA ever of our prehistoric ancestors

The “bone pit” at Sima de los Huesos in northern Spain is an Eldorado for archaeologists. A team of Spanish researchers discovered and reassembled almost 30 skeletons here. Scientists at the Max Planck Institute for Evolutionary Anthropology in Leipzig have now extracted the DNA from two grams of powdered bone and decoded the mitochondrial genome. From the differences when compared with the genomes of Neanderthals, Denisova hominins and humans alive today, the scientists calculate that the prehistoric skeletons from Sima are around 400,000 years old. They and the Denisovans – a recently discovered Asian relative of the Neanderthals – also shared a common ancestor some 700,000 years ago. It’s possible that the prehistoric dwellers in Sima were related to the population from which both the Neanderthals and the Denisovans were subsequently descended. (Nature, December 4, 2013)

Cracking Wood

In a simple parallel process, the components of lignin can now be extracted for practical use

It looks like it could one day be easier to exploit wood as a source of raw materials. A team of chemists working with Roberto Rinaldi at the Max-Planck-Institut für Kohlenforschung (coal research) in Mülheim an der Ruhr found an efficient way to render the components of the biopolymer lignin usable. Lignin stabilizes plant cells and contains organic compounds that are of great value to the chemical industry, for example for the manufacture of biofuels. Until now, however, it has been difficult for the industry to access the component parts. The chemists in Mülheim developed a method by which to split the tightly interwoven chain molecules of lignin, while at the same time benignly removing the oxygen from its components. They are then left with aromatic substances that are easy to separate. (Angewandte Chemie International Edition, September 12, 2013)
Europa’s Ocean Heat Pump

Jupiter’s moon Europa is a bizarre and quite literally cool beauty: A delicate network of furrows several kilometers long cuts through its outer ice shell like the cracks in an old oil painting. The unusual pattern is particularly pronounced around the equator. But how did it originate? Researchers have long suspected that an extensive ocean of saltwater lies beneath the moon’s surface. And this ocean could just be the key to the puzzle. Scientists at the University of Texas and the Max Planck Institute for Solar System Research discovered that, in the vicinity of the equator, warmer water is rising from deep within Europa. Their model calculations show that movements in the water are driven by temperature differences. These convection currents are stronger in the equatorial region than at the poles, and the ice cover is more effectively heated at lower latitudes. However, just how this heat causes the cracks in the ice layer has still not been fully explained. (Nature Geoscience, December 1, 2013)

More Greenhouse Gas than Ever

The atmosphere contains more carbon dioxide than at any time since measurements began

Mankind is pumping more and more carbon dioxide into the atmosphere: Measurements by the Global Carbon Project in which Sönke Zaehle of the Max Planck Institute for Biogeochemistry is participating show that, in 2012, burning fossil fuels and other human activity released 35 billion tons of the climate-warming gas. Annual emissions have increased by 58 percent since 1990 and are now higher than ever. As a result, in May 2013, the carbon dioxide content in the air rose above 400 ppm (parts per million) for the first time. Analyses of ice cores from Antarctica show that the atmosphere has never contained so much greenhouse gas in the past 800,000 years as it does now. Given the projections for global economic growth, the researchers expect emissions to increase still further to 36 billion tons in 2013. (Earth System Science Data Discussion)

Flies Prefer Oranges

Drosophila’s preference for citrus fruits protects it against parasites

If there are tiny flies circling over the fruit bowl in the kitchen, it’s the oranges they’re heading for. The fruit fly Drosophila melanogaster prefers to lay its eggs on these citrus fruits, as researchers at the Max Planck Institute for Chemical Ecology in Jena observed. When the larvae hatch, they feed on the microscopic yeast fungi on the orange peel. The researchers’ findings indicate that the aroma components limonene and valencene are key in the flies’ choice of where to lay their eggs. They detect the aromas with a single odorant receptor. This preference on the part of the fruit flies is a defense against one of their greatest enemies, the parasitic wasp Leptopilina boulardi, which lays its eggs on the fly larvae. The same scent that attracts the flies also repels the wasps. Why the wasps avoid citrus fruits is puzzling, given that their scent should really act as a signpost to the source of food. (Current Biology, December 2013)
Working to the Beat

Making music aids physical effort

At first sight, music and hard physical work don’t appear to have much in common. Yet the origins of blues and gospel show that that’s not true: slaves in the cotton plantations and prisoners sentenced to hard labor sang as they worked, and integrated the sounds of their exertions into their music. In the past, it was supposed that music was simply a distraction. However, scientists at the Max Planck Institute for Cognitive and Brain Sciences in Leipzig have now discovered that music also reduces the actual effort. They made their discovery with the aid of what is known as jymmin technology, using fitness equipment that turns movements into music. The effect is to allow sports participants to make music interactively. In the studies conducted by the researchers in Leipzig, the majority of subjects not only felt the effort less keenly when the jymmin machines were making music, but their muscles also consumed less energy and were therefore more effective. It’s possible that the musculature is better controlled at an emotional level as a result of the music-induced ecstasy. This effect of music could even be a previously undiscovered reason for its very origins. (PNAS, October 14, 2013, published in advance online)

Cosmic Oddball

An atypical asteroid is rotating so fast that it is losing mass and forming several tails

There are some bodies that have a very disturbing effect on the order in the planetary system – P/2013 P5 is one of them. With at least six tails, it may look like a comet, but it orbits the Sun within the asteroid belt between Mars and Jupiter, and it can’t be unequivocally assigned to either category. An international team including scientists at the Max Planck Institute for Solar System Research has been taking a closer look at this puzzling object through the Hubble space telescope. Their diagnosis is that P/2013 P5 is an active asteroid that rotates so rapidly under the radiation pressure of the Sun that it emits matter into space. Normal asteroids, in contrast, are robust celestial bodies that already lost their volatile components, such as water, billions of years ago under the influence of the Sun, and now hardly change in appearance. (Astrophysical Journal Letters, November 7, 2013)
“If you work hard for something, then it will turn out the way you want.” Sandra Kortner, group leader at the Max Planck Institute for Physics.
The Particle Hunter

Some enthusiastically call it the “discovery of the century” when they speak of the discovery of the Higgs boson at Europe’s CERN laboratory in the summer of 2012. As a group leader at the Max Planck Institute for Physics in Munich, Sandra Kortner is closely tied to this research—all the while managing her role as the mother of two small children.

She is blond and rather petite. She just seems a little tired out, like most young mothers. After all, little Adrian, born just a few months ago, presumably demands Sandra Kortner’s full attention. But as we sit in her office discussing the quest to discover the Higgs particle, Adrian and his brother David, who is two years older, are at home enjoying the attention of their doting grandparents.

So we are undisturbed during our meeting at the Max Planck Institute for Physics in Munich. That’s where the 39-year-old Croatian is hot on the trail of a recently discovered particle: the Higgs boson. She has headed a small research group since 2009 under the Max Planck Society’s Minerva Program. She was recently given a permanent position. It’s easy to see that she is relieved about this. After all, the path that led her there wasn’t always easy.

The specter of uncertainty about what the coming months would bring professionally and financially always lurked in the background. “You often don’t know right up until the last second. If you want to stay in science, it’s really expected that you relocate frequently—to wherever there happens to be a position open, and then it’s normally limited to just a few years,” says Sandra Kortner. “That’s not easy, especially when you have a family.”

FASCINATED BY THE STARRY SKIES AS A CHILD

She herself was close to leaving research and going into industry a couple of times already. But then it always worked out again with another position—albeit one with yet another fixed term. She undoubtedly succeeded at this in part because she believed in herself and never lost sight of the big picture. Her personal recipe for success: concentrate on the research and just don’t think about the external circumstances. “If you work hard for something, then it will turn out the way you want, or at least pretty close. You can’t lose hope,” believes the scientist.

Even as a child, Sandra Kortner found the starry skies fascinating and was interested in astronomy. Later, at school, she was particularly good in subjects like math and physics. It wasn’t difficult, then, to choose a major, and she began her physics studies in her home town of Zagreb. She soon came to prefer nuclear and particle physics, so her Croatian mentor, Kreso Kadija, who himself had previously worked at the Max Planck Institute for Physics, sent the then-25-year-old student to Munich for two months.

There, she gained her first practical experience while working on her thesis. The young researcher’s enthusiasm for particle physics continued. Later, between 2001 and 2005, she completed her doctoral dissertation in Hubert Kroha’s research group at the Max Planck Institute, in cooperation with her alma mater in Zagreb and her dissertation supervisor, Kadija.

Kortner soon came to love the Bavarian capital and she has long since grown to feel at home here. The cultural differences with Croatia aren’t all that great, she says. The locals take a very pragmatic approach to day-to-day

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TEXT FELICITAS MOKLER

Photo: Denise Vernillo
life, which reminds her of the Croatian mentality. In addition, she really enjoys the fact that Munich offers all the advantages of a big city, such as cinema, theater, museums and shopping, while simultaneously having the homey character of a small town: “The village with a million inhabitants, as they say, with a fascinating variety of personalities,” she says.

Also, it isn’t that far to travel from here to her native country. “That was an ideal combination. I was able to commute between Zagreb and Munich when something had to be discussed at the other place; or if I wanted to visit my family, or if they wanted to visit me.”

**A CONSTRUCTION KIT OF QUARKS, LEPTONS AND GAUGE BOSONS**

As a doctoral student, Sandra Kortner was involved in setting up one of the two experiments that, in 2012, were used to prove the existence of a new particle, the Higgs boson: the ATLAS detector at CERN. This boson is crucial to the Standard Model of particle physics. This model maps out a place for all the known building blocks of matter. The construction kit consists of six quarks, which make up, for instance, protons and neutrons; six leptons, which also include the electron and the associated neutrino; and the mediator particles of the fundamental forces with which the particles interact with one another: the gauge bosons, such as the photon.

“The Standard Model is a theory that has been brilliantly confirmed by all experiments thus far,” explains San-
Another, its lifespan is simply much too short. When the Higgs boson decays, the secondarily produced particles can be of a different nature. One path, for instance, is a cascade ranging from the W and Z bosons of weak interaction to certain leptons, such as the longer-lived muons. These can be detected in special muon chambers.

**THE DRIFT CHAMBERS MUST BE ABSOLUTELY DUST-FREE**

On the way from her office to the institute’s clean rooms, where muon chambers are designed and built for the ATLAS experiment, Sandra Kortner uses a model to explain what such a detector looks like and how it works. Not one speck of dust can be allowed to contaminate the aluminum drift chambers that will later be traversed by charged particles. The wires in the aluminum tubes, to which a voltage will eventually be applied in order to deflect the particles, must be positioned with a precision of 10 to 20 micrometers (thousandths of a millimeter). All of the components are specially designed and constructed for this experiment – nothing is industrially manufactured in serial production.

“Since muons lose very little energy in the detector, they can traverse it completely. That is why the muon chambers are built at the very edge of the detector. Further inward are devices for detecting other particles, such as photons, electrons and protons,” explains Sandra Kortner. From the values measured in various detector sections, the researchers can then conclude which type of particles they are and at which location and with what energy the particles were produced.

Kortner was personally involved in the construction of the first muon chambers for ATLAS during her doctoral studies, and conducted the test measurements on it at CERN. Today, in contrast, she simulates particle paths on the computer and compares her results with the measurement data.
CERN and the Max Planck Institute in Munich, which involved a total staff of around 300, from October 2010 to October 2012. That undertaking required a good deal of assertiveness, tenacity and organizational talent.

A YOUNG MOTHER – YET DOING RESEARCH AROUND THE CLOCK

The scientist initially spent about half of her working time at CERN, near Geneva, and the other half in Munich. When the search for the Higgs boson really kicked off in July 2011, her son David was born. She then cut back on her travels. Nevertheless, not a day passed without her reading her e-mails, and many days were filled with team meetings about the findings. Sandra Kortner was doing research around the clock.

That was no mean feat for a young mother. And still: “Modern telecommunications options are a great help. For instance, we can hold telephone and video conferences. For one thing, that saves a lot of time that would otherwise be spent on traveling. For another, I had the opportunity to work from home a lot. That let me spend some time with my son in between meetings.”

A daycare center was, and still is, out of the question. They are in very high demand in Munich, and there aren’t enough of them to meet this demand. But she and her husband, Oliver, who likewise works as a physicist at the Max Planck Institute, split their parental leave. And then there are the in-laws, who live nearby and were also already helping out back then. In this way, Kortner was able to fully attend to her responsibilities as coordinator of the ATLAS Higgs Group despite her young family.

The effort paid off: Since 2010, there have been new research findings to discuss every three months. Around Christmas 2011, the first signs appeared in the jumble of data showing that the events became more frequent at the appropriate energy of 125 giga-electron volts. In March 2012, the signal was initially somewhat weaker again, and then, in late June, somewhat stronger than expected. The data analysis showed...
relatively reliably that there must be a previously unknown particle cavorting about at the energy mark predicted for the Higgs boson. On July 4, 2012, the findings were to be officially announced at a press conference.

“Of course we suspected and hoped there was something there – after all, our measurements showed a clear signal. But we also didn’t know that until a week before the scheduled press conference, and we didn’t yet know the results of the CMS experiment. It was a terribly exciting moment,” says Sandra Kortner, and a bit of the excitement from that time can still be heard in her voice.

The CMS detector is likewise used for the search for the Higgs particle, and is designed similarly to ATLAS. But the two research groups involved in these experiments work entirely independently of one another. No member of one group knows what data the other has just measured. In this way, the scientists can preclude systematic errors in their analyses.

EVERYONE WAS SO BUSY THEY FORGOT TO CELEBRATE

Kortner and her colleagues were thus overjoyed when it turned out that the data sets from the two experiments delivered exactly the same result. “More than anything, that was an incredible feeling of fulfillment. After ten years of data analysis and model calculations, it was simply incredible. Everyone on the CERN premises was beaming,” recalls Sandra Kortner. Right up to the last minute, the scientists were so absorbed in their work that no one had really given any thought to celebrating. So they improvised. Whoever had a bottle of champagne or sparkling wine to spare brought it out.

But the next day was business as usual. The research had to go on. A lengthy vacation, for instance in her native Croatia, wasn’t possible. As yet, the newly discovered particle hadn’t been definitively characterized. For example, no one knew its spin properties – an important parameter in particle physics in order to be able to classify a particle. The researchers have since
proven that the particle has a spin of zero, as predicted for the Higgs boson.

In October 2013, Peter Higgs and François Englert were awarded the Nobel Prize in Physics. Sandra Kortner was pleased about this, of course. She finds it very satisfying to know “that your own long years of work contributed to finally confirming a theory.” And she is certain that all the other 6,000 or so staff involved in the ATLAS and CMS collaborations share this feeling.

Nevertheless, the analyses of the Higgs particle are far from complete. To get to know the boson better, the scientists are currently working on an expansion of the experiment. The LHC is expected to run about another ten years at nearly twice the energy. After that, it’s due to receive an upgrade to allow it to take measurements at even higher collision rates.

For Sandra Kortner’s day-to-day research, this means, above all, continuing to simulate the decay of the Higgs boson. Such calculations are necessary in order to be able to interpret the measured data correctly. After all, such high-energy collisions in the accelerator create all kinds of particles, and in much greater numbers than the Higgs particles being sought. These other particles, in turn, also quickly decay into secondary particles, and all of their traces show up in the measured data.

“It’s like the proverbial search for a needle in a haystack – or even more drastic: imagine an Olympic swimming pool filled with sand. The number of grains of sand corresponds to the number of particles created when a collision occurs. Only ten to a hundred of those are Higgs bosons,” explains Kortner.

**IT’S ONLY NATURAL THAT HER PARTNER SUPPORTS HER**

After a couple of months of caring solely for Adrian, she is now working again, initially on a part-time basis. After all, while her family is what’s most important to her, she is a full-blooded physicist, and completely foregoing research wouldn’t work for her at all. In a couple of months, her husband will start working part-time for six months so that she can be completely available for the research. She greatly appreciates the fact that her partner so naturally supports her in this way.

Reconciling career and family requires effort. It means continually replenishing the reserves. “The best way for me to do that is on vacation at my family home in a small village near Zagreb, with all the relatives,” she says. And when the children are a bit older, she dreams of driving to the Croatian coast again with them and her husband, as she loves the sea – and also because it holds a bit of nostalgia from her own childhood.

“For a quick getaway from everyday life at home, I like to go for a walk with the family. I just really like to be out in nature,” says Sandra Kortner. And even then, she is on a journey of discovery – albeit with the roles reversed. Now it is her two-year-old son who heads up the research. “This is the age at which children begin exploring their surroundings on their own and asking questions. We then learn to discover the world anew through their eyes.”
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NETWORKING FOR SCIENCE
It was an historic moment as, in 1807, the workers drove their shovels and pickaxes into the muddy ground near Antwerp, Belgium one last time. At Napoleon’s behest, they had created a connection between the River Scheldt and a branch of the Rhine, just 35 kilometers away at this point, thus bringing to fruition the emperor’s plan to link navigation along the Rhine with the then-French port of Antwerp. The fact that their work was also responsible for the birth of a new species of fish would have gone unnoticed were it not for the fact that, almost 200 years later, ichthyologists discovered a type of fish previously unknown in the Rhine.

The artificial waterway between the Scheldt and the Rhine opened a gateway to the east for the sculpin *Cottus perifretum*. Unfazed by the turmoil and wars in Europe in the 19th and 20th centuries, the small bottom-dwelling fish saw its chance. It let the current carry it out of its habitat in the upper reaches of the Scheldt tributaries,

The sculpins of Arne Nolte, head of a research group at the Max Planck Institute for Evolutionary Biology in Plön, near Kiel, are no beauties; yet these unprepossessing fish, first discovered in the Lower Rhine in the 1990s, hold a special fascination for him. After all, these particular sculpins are hybrids, the shared offspring of two species.

TEXT HARALD RÖSCH

**Sculpin Liaisons**
swam through the new canal, and ended up in the Rhine estuary.

In fact, *Cottus perifretum* can’t survive for long in large rivers, as it doesn’t like mud at all. The water there also gets too warm in summer, and there’s not enough oxygen. In the Rhine, however, the newcomer from the Scheldt met a close relative, the Rhine sculpin *Cottus rhenanus*. Its name is misleading in that *Cottus rhenanus* doesn’t live in the Rhine itself, but in the tributaries of the Middle and Lower Rhine. As with its more westerly counterparts, however, it can happen that individual fish get carried down in the main current from the headwaters of the tributaries. Somewhere in the Lower Rhine region, shortly before the river empties into the North Sea, the two species managed to produce offspring despite the unfavorable conditions.

Helped by massive ecological changes in the lower reaches of the Rhine, the offspring of this liaison have been hugely successful since then, conquering almost the entire Rhine. Also known as bullheads, the sculpins have migrated upstream at a rate of five to ten kilometers per year, reaching the Upper Rhine at Karlsruhe and the lower reaches of the Main river.

**NO PLACE FOR SCULPINS**

Arne Nolte has been tracking the spread of the new sculpins, which were first sighted some 20 years ago in the lower reaches of the Rhine. At that time, fish experts were at a loss, insofar as sculpins had never been observed in a similar habitat, let alone one that had been so significantly altered by human activity. “It was like finding brown trout in the Rhine, or carp in a mountain stream,” says Nolte; but that wasn’t the only surprise. Using genetic analysis, Nolte verified in 2005 that the newcomers were the result of crossbreeding, or hybridization, as biologists call it. Although they look more like the Scheldt parental species on the outside, genetically they are a mixture of *Cottus perifretum* and *Cottus rhenanus*.

The fact that these crossbreeds can apparently conquer a new habitat with more success than their parent species goes against the conventional wisdom that has long prevailed among evolutionary biologists. “Hybrids used to be seen as slip-ups that weren’t really intended in nature. They were thought of as low-value rejects that couldn’t reproduce even if they arose in the first place,” explains Nolte. A prime example of this is the mule, a sterile creature arising from the hybridization of a horse and a donkey.

The reason for this attitude lies in the definition of a biological species as set out by biologist Ernst Mayr in the 1940s: a community of individuals that reproduce among themselves. All individuals that can come together to pro-
produce viable offspring would then belong to the same species. However, it has since become apparent that Mayr’s definition is too restrictive and disregards many clearly different species.

Botanists were quick to realize that different plant species often interbreed and yet still generate viable offspring. Zoologists weren’t so quick off the mark, but the new sculpins in the Rhine are just one example of the fact that animal species, too, regularly intermingle in nature. Not only that, but Nolte is convinced that hybrids may play a central role in the emergence of new species. It is estimated that approximately one out of every ten fish and bird species hybridizes with another species. “Hybrids are more than just accidents of nature; on the contrary, they may have made a major contribution to biodiversity on Earth. Were it not for that intermingling, we would have fewer species,” says Nolte.

**HOW IS A SPECIES BORN?**

For a new species to develop, the gene flow within a species must be prevented or at least restricted. This is the case when individuals are spatially isolated from the population, by a river or mountain range for example (**allopatric speciation**). The two groups then evolve differently so that, given sufficient time, two different species emerge. Scientists have often observed this form of speciation in birds.

However, new species can also develop without spatial separation. In a given population, individuals with an extreme characteristic may be ideally adapted to the environment, such as when small individuals specialize in one food type and large individuals in another. In this kind of **sympatric speciation**, the gene flow is inhibited if the two groups prefer their own type and no longer reproduce with the other. This process has been well documented particularly for fish species and insects.

Genetic exchange between populations can also be prevented if, for example, they specialize in different habitats or develop different courtship behavior, mate at different times, or if the hybrids are inferior to both original populations.

This would suggest that hybridization constantly provides for new genetic variants, especially between closely related species. “Hybrids are more than just accidents of nature; on the contrary, they may have made a major contribution to biodiversity on Earth. Were it not for that intermingling, we would have fewer species,” says Nolte.

**A BIG SMORGASBORD**

Nolte hopes the sculpins will show him how hybrids generate new species, but he began by focusing on the diversity of European fish fauna. This had received only cursory attention until the 21st century, the first comprehensive and systematic compilation of European fish being published in 2007. Little wonder, then, that the nature of the relationships between sculpin populations had attracted little attention. Ichthyologists had often lumped the sculpins of Central Europe together in one basket, referred to as the *Cottus gobio* complex. Working at the time with Maurice Kotitelat and Jörg Freyhof at the Alexander Koenig Research Museum in Bonn, Nolte identified three different species out of that conglomeration, all of which occur in the Lower Rhine region and in directly neighboring rivers.
Arne Nolte has had an interest in fish since his childhood years. Cichlids, loach, scalar, killifishes – his aquariums were a veritable “Who’s Who” of popular pet fish. His inventory comprised up to 40 different tanks at its height; even the vegetables had to be moved out of his parents’ greenhouse to make room for the fish. It was already clear to the budding biologist that he wanted to work with fish. Since his university in Oldenburg offered no such opportunity, he traveled through Europe on his own and collected sculpins in order to identify them. As a result, practically no one knows these fish as well as Nolte.

His analyses soon showed that morphology alone would no longer be sufficient for species identification. Genome analysis became an increasingly important tool for identifying taxonomic relationships. In Diethard Tautz’s laboratory at the University of Cologne, Nolte appropriated the molecular biology equipment that he would use for sculpin analysis. In 2008, Tautz, by then Director at the Max Planck Institute in Plön, called on him to join his team.

A look at the sculpin genome uncovered what wasn’t visible to the naked eye: the sculpins that turned up in the Rhine are genetic hybrids. Since that discovery, genetic analysis has shaped Nolte’s day-to-day research. With its help, he hopes to find out how the hybrid sculpins evolve into a new species in the new habitat, and what makes them so successful.

Nolte seldom goes out on fishing trips now, because his analyses require that the fish be held under controlled conditions and that they interbreed in a specific way. Consequently, his preferred subjects swim in the fish room of Plön’s Max Planck Institute, in neat rows of aquariums supplied with fresh water from Schöhsee, a nearby lake.

It’s a stroke of luck for scientists to be able to observe the birth of a species at such an early stage. In many cases, biologists study populations that have already been diverging for thousands or even millions of years. “Our hybrid lineage is probably no more than 200 years old. That’s quite unique,” says Arne Nolte.

**HYBRID FITNESS**

First, the researchers wanted to clarify whether the offspring of the hybrid sculpins inherit a genetic handicap. When hybrids reproduce, parts of the genotypes from both parent species are mixed together, and specific mutations that affect the viability of the hybrids can occur. Sometimes, for example, selfish genetic elements called transposons are activated. These are jumping DNA segments that are integrated at some point in the genome and interrupt genes. In many animal species, male hybrids are less viable because they have only a single copy of the X

### Graphic: designergold, based on original material from the MPI for Evolutionary Biology

**Sculpin family tree:** A comparison of six especially variable regions in the genome shows that the hybrid sculpins (red) form a genetically distinct group from both parent species. They differ to practically the same degree from both Cottus perifretum (purple) and Cottus rhenanus (blue). Moreover, the hybrids are genetically more similar to one another than the parent species, which are subdivided into individual lines. (The numbers correspond to the find sites on the map on page 60.)

**Without hybrids, there would be fewer species on Earth.**
and Y sex chromosomes, so genetic defects have an immediate impact on male animals. However, the researchers in Plön haven’t detected any harmful genetic effects in the hybrid sculpins.

This means that the first hybrids weren’t at a genetic disadvantage after *Cottus perifretum* and *Cottus rhenanus* met in the Rhine. However, being no worse than the parent species isn’t enough. After all, the parent species hadn’t managed to survive long-term in the Rhine.

Consequently, the crossbreeds must have mastered something that was beyond the abilities of their predecessors. Nolte and his colleagues have yet to identify exactly what that is. “We assume that the hybrids are better able to adapt their metabolism to higher temperatures. They tolerate warmer water and grow faster in it,” he says.

**CLUES IN THE GENOME**

Once again, the genome contains important clues. Some 500 genes are active to different degrees between the parent species and the hybrids, and these genes hold the secret to the hybrids’ success. Moreover, today’s hybrid sculpins are no longer genetically identical to the original hybrids. A comparison between wild hybrids and recent laboratory crossbreeds yielded marked differences in their genomes. This means that the sculpins currently living in the Rhine have already evolved further and adapted to the prevalent environmental conditions.

Arne Nolte wants to delve still deeper, and the European Research Council (ERC) has furnished him with almost 1.4 million euros to do just that. Over the next five years, he plans to conduct extensive genetic analyses to find out which genetic mutations enable the hybrids to survive in large rivers, and what ecological advantages those mutations confer.

The impact of evolution on the hybrids in the Rhine can be observed in natural hybrid zones, areas where the hybrids living in the large rivers encounter the native sculpins in the tributaries. Nolte and his team have examined several of these hybrid zones along
Photos: MPI for Evolutionary Biology (3)

top: Arne Nolte loves to busy himself with fish on his own time, too. Here he poses with a freshly caught brook trout (*Salvelinus fontinalis*) from the Sainte-Marguerite River in Quebec, Canada.

bottom left: Jörg Freyhof (left) and Arne Nolte scour the stream for sculpins in the Pleisbach, a tributary of the Sieg in North Rhine-Westphalia. Sculpins live on the beds of streams and hide under stones and branches. They are poor swimmers, having no swimbladder, so they use jerky zigzag movements to flee from would-be catchers.

bottom right: The fish room at the Max Planck Institute in Plön houses dozens of aquariums with sculpins from different populations. Scientists can observe the lives of the fish and carry out crossbreeding experiments in these shallow tanks, which have been furnished with river gravel and shards of pottery as hiding places. The temperature and day length in the room can be regulated precisely, because the sculpins need cool water and seasonal fluctuations in order to survive and reproduce.
the Sieg river, which flows into the Rhine at Bonn. The headwaters of the Sieg tributaries contain only *Cottus rhenanus*, while the Sieg itself yields the hybrids with *Cottus perifretum*. At the river mouths, the two lineages meet and propagate, and backcrossing occurs, giving rise to secondary hybrids.

**CAUGHT AT RIVER MOUTHS**

Parent species, hybrids, secondary hybrids – the taxonomic relationships could now become impossibly complex, but the secondary hybrids seem to have a problem. They colonize only the river mouths in the long term – areas where hardly any other sculpins occur. They seem unable to disperse from there, because while the sculpins in the Sieg have spread at a rate of approximately four kilometers a year, the hybrid zones have remained about two kilometers wide for years. The conclusion is clear to Nolte: “Tributary outlets constitute ecological boundaries, and thus barriers to dispersal. The secondary hybrids are inferior to both the original Rhine sculpins in the headwaters and the Rhine-Scheldt hybrids in the main rivers.”

Genetic analysis of the fish from hybrid zones provides a further pointer that natural selection determines the dispersal of secondary hybrids. It has shown that the secondary hybrids are both viable and able to reproduce. They breed with one another and, at the edges of the hybrid zones, with the parental lines, resulting in a true hybrid swarm. This means that the expansion of hybrid zones isn’t limited by genetic causes alone. The only possible explanation is that hybrids in the transition zones are less adapted to the habitats of their parents. They can establish themselves only at river mouths, where conditions change abruptly.

The findings from hybrid zones along the Sieg are important to Nolte in another regard, as well: “They are an example of the fact that hybrids are inferior to the parental lines in their original habitat when in direct competition with them. This is especially true when the habitats are intact.” This news will reassure conservationists, who warn of the risk of bastardization of fauna through the release of cultivated lines. It confirms observations of pike, char and trout, which revealed that cultivated fish that escaped have left practically no genetic traces in wild populations.

A similar case is that of *Betta splendens*, a fighting fish that is popular with aquarium enthusiasts. In its native Thailand, breeders cultivate colorful variants with eye-catching fins for the aquarium market; but for centuries now, they have also produced aggressive, short-finned variants for fighting contests. It’s safe to assume that cultivated forms have repeatedly escaped over the years and mixed with wild variants. Some ichthyologists have even gone so far as to state that the original *Betta* is extinct – an unlikely scenario, since cultivated forms and their hybrids don’t stand a chance against their indigenous relatives in the wild.

**HYBRIDS FILL NICHES**

The concept that hybrids are less adapted to the environment than their parent species is valid only in relation to the original habitat. They are often better at occupying new habitats, as revealed by the sculpins in the Rhine. “Hybrids are better at conquering new territory, and that’s why they play such an important role in speciation. With their genomes from different lines, they deliver new templates for evolution to play with,” says Arne Nolte.

Not only do hybrids colonize new habitats more easily, but they are also at an advantage if the original environment changes. In such situations, new adaptations are required and the hybrids can outflank the parent species.
One such changing habitat is the Rhine. Straightened by humans and corseted by dams and shoreline stabilization, the extent of change has accelerated over the last 20 years. Since water protection in Germany was enhanced after a series of chemical spills in the 1980s, water quality in the Rhine has seen continual improvements, and the river is once again home to a number of species that had vanished. At the same time, however, the amount of living organisms in the Rhine has fallen, since there are now fewer nutrients available.

In addition, a number of animal and plant species have been introduced by humans or have migrated there in the course of climate change. In fact, the Rhine has experienced several waves of migration within just a few years, and non-indigenous Asian clams, amphipods and bristle worms now dominate large parts of its ecosystem. “This type of habitat upheaval gives hybrids the opportunity to fill new niches, and it is probable that climate change will further accelerate the emergence of new species from hybrids,” says Nolte.

In other words, hybrids aren’t just an undesired byproduct in the interplay between species, but are ubiquitous in the natural world as an indispensable driver of evolution. Hybridization even played its part in the evolution of modern humans. *Homo sapiens*, Neanderthals and perhaps other human types interbred during the course of their history, so humans also benefited from foreign genetic material as they spread across the globe.

Consequently, the advance of the sculpin hybrids in the Rhine doesn’t worry Nolte; he considers it a completely natural process. In fact, he is far more concerned about other invaders. In recent years, black spotted gobies, bighead gobies, racer gobies and tubenose gobies have been migrating upstream from the Danube estuary to the Black Sea. They entered the Rhine via the Rhine-Main-Danube Canal, among other channels, and are spreading like wildfire.

**Gobies with a Migration Background**

Gobies are in direct competition with Nolte’s sculpins. These are especially large and powerful fish that avail of a broad spectrum of food sources and are capable of winning through against other species. Bit by bit, the newcomers are displacing indigenous fish species. In some places, the invasive gobies now comprise over 70 percent of catches from the river bed. Large populations of hybrid sculpins are still found in the main tributaries of the Rhine, but there is a risk that the new expansion will put an end to the furtive spread of the hybrids, less than 200 years after it began. The specimens in Nolte’s fish room would then be the last of their kind, survivors of an initially successful, but ultimately failed experiment of nature.

**TO THE POINT**

- In nature, different species regularly breed with each other. Under certain conditions, these hybrids can give rise to new species.
- The combination of the genomes of both parent species can give hybrids new characteristics and abilities, enabling them to colonize new habitats more easily.
- The parent species generally predominate in the original habitat, and hybrids can’t prevail there. However, this applies only in the case of undisturbed habitats. Shifts such as climate change increase the hybrids’ chances of survival.

**GLOSSARY**

**Biological species:** Classification by species is an attempt by scientists to describe the diversity of nature. However, living creatures differ to varying degrees, so the dividing lines researchers draw between species are necessarily arbitrary. Today, there are more than 20 different definitions of species. They divide organisms on the basis of external characteristics, genes, behavior, physiology, or their ability to reproduce. According to one prevalent concept, all individuals that are capable of breeding together and producing fertile offspring belong to one species. Be that as it may, no definition has yet emerged that categorizes individuals consistently in every case.

**Hybrids:** In the strict sense, hybrids are the offspring resulting from the cross-breeding of individuals that differ from each other in one or more characteristics. In general, though, the term refers to reproduction between different species. The colloquial expression “half-breed” is a bit of a misnomer, since hybrids may be more like one parent. Some hybrids even surpass their parental types, or display completely new characteristics.

**Hybrid swarm:** A hybrid swarm occurs when hybrids continue to breed with the parental types they originally evolved from. Their offspring interbreed with each other, with their hybrid parents and with the parental types, giving rise to many different genetic lines.
Normally, Peter Benner and his colleagues at the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg work on complicated numerical methods to optimize the automatic control of technical systems and equipment. Recently, however, their research was applied to resolve a political conflict centering around drug cultivation, herbicide spraying and border violations in South America.

Back in 2008, Peter Benner and his former doctoral student Hermann Mena were presented with a very unusual challenge: they were asked to calculate the drift of the herbicide glyphosate in the border region between Colombia and Ecuador. Ecuador had just brought a lawsuit against Colombia in the International Court of Justice. It accused Colombia of having for years sprayed coca plantations near the Ecuadorian border with glyphosate, and claimed that the poison had also settled on Ecuadorian soil. The lawsuit was the culmination of a conflict with a long history. The spraying campaign was launched in 2000 as part of Plan Colombia, a US-funded program initiated in 1999 to fight drug cultivation across Colombia. The object was to destroy the coca plants that provide the raw material for cocaine by spraying them with the non-selective herbicide glyphosate. Until 2005, Colombian aircraft circled at least once a week over the forested mountains in the south of Colombia, spraying the herbicide over the coca fields.

THE WAR ON DRUGS HAD SIDE EFFECTS

In doing so, Ecuador claimed, the Colombian aircraft had repeatedly committed border violations. The herbicide not only caused the coca plants to wither, but also killed corn crops and plantain and yuca plants in Ecuador – at least according to inhabitants of the border region. They also reported damage to their health, including skin irritations, respiratory disorders, gastrointestinal problems, dizziness and headaches.

In 2005, the two countries reached an agreement: a 10-kilometer strip along the border on the Colombian side was
to remain a glyphosate-free zone. Officially, the crop-spraying aircraft haven’t been in operation since 2007. Nevertheless, Ecuador has repeatedly accused its neighbor of violating the agreement. By bringing a lawsuit against Colombia in 2008, Ecuador wanted to put an end to the incursions once and for all.

However, it turned out to be very difficult to prove the accusations. The border runs through jungle terrain, the airspace isn’t monitored, and glyphosate decomposes rapidly so that, after three weeks, it is no longer detectable in the environment. Thus, no traces of the substance could be found when people from the competent authorities, following up on complaints from inhabitants, traveled to the border region to collect samples.

**A YOUNG MATHEMATICIAN FROM ECUADOR**

The question was thus how to prove the alleged border violations. This is where Hermann Mena enters the picture. Formerly an associate professor at the Escuela Politécnica Nacional (EPN) in the Ecuadorian capital of Quito and now assistant professor at the University of Innsbruck in Austria, Mena was tasked with carrying out a research project for the Ecuadorian Science Foundation SENESCYT.

Hermann Mena and Peter Benner had met in 2003 during a DAAD-sponsored program between TU Berlin and the Escuela Politécnica Nacional. The aim of the program was to expand postdoctoral education in mathematics in Ecuador. Benner gave an intensive...
course in applied mathematics in Quito and was able to take Mena on as a doctoral student. In 2007, Mena became the first mathematician to be awarded a Ph.D. by an Ecuadorian university.

USING MATHEMATICAL FORMULAS TO COLLECT EVIDENCE

In order to present iron-clad scientific proof against Colombia, the Ecuadorian government launched a total of four research projects. Two of them concerned the long-term effects of glyphosate on humans and amphibians. A third investigated whether the substance has long-term effects on plant growth. The fourth project dealt with applied mathematics: a computer program was to numerically simulate the drift of the herbicide sprayed within the border zone.

It’s no big deal for mathematicians to calculate the mixing of two substances. To do so, they use what are known as convection-diffusion models. The numerical equations for such models describe how particles interact and spread as a result of random motions and large-scale currents.

“It’s a classic. Such models are used, for example, in meteorology and chemical engineering, and also in various ways at our institute,” says Peter Benner, now Managing Director at the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg. “Specifically, the aim here was to determine whether and, if so, under what conditions the sprayed glyphosate could reach Ecuador.” Hermann Mena was appointed project head. He
recruited his former doctoral supervisor as an advisor, because at the time there were still no scientific institutions in Ecuador capable of carrying out such a project.

The two scientists were faced with the task of calculating the drift of the sprayed herbicide droplets. This isn’t a daunting problem in itself: “The mathematical description of the basic problem is standard, and good software exists for solving it,” says Benner. To adapt the software to their specific needs, the researchers worked with Jens Lang from TU Darmstadt.

Several physical processes determine the movement of droplets: first, diffusion, or in other words, random motion; second, convection, that is, transport via air currents. A third factor, turbulence, also plays a role, for example in the wake generated by an aircraft. “But we didn’t take turbulence into account because, otherwise, the calculations would have required too much computing power,” says Hermann Mena.

SIMPLE MODELS THE COMPUTER CAN HANDLE

Simplifying complicated mathematical models without sacrificing the accuracy of the simulation results is Peter Benner’s forte. He heads the Computational Methods in Systems and Control Theory Group at the Max Planck Institute in Magdeburg. Researchers there investigate complex technical processes, particularly in the fields of chemical engineering and biotechnology. With their simulations and models, Peter Benner and his colleagues are a great boon to chemical engineers. “Computer simulations are increasingly being used to optimize the control of complex systems,” he says.

For example, when engineers develop a chemical process, they have to consider many factors. How rapidly do the substances mix in the reactor? What is the optimum mixing ratio? Which catalyst is suitable? “Engineers generally have a good grasp of how to proceed, but mathematicians can often improve the yield by several percentage points,” Benner points out. In the chemical industry, that can mean savings of millions of euros.

But to achieve this optimization effect, the models have to run countless times with many different parameters. Because that still takes too long even with today’s computers, Peter Benner and his fellow scientists develop so-called surrogates – simplified models that are automatically calculated by mathematical methods, but whose accuracy is sufficient for the task at hand.

“It’s a bit like the approach taken in digital photography,” says the Max Planck Director. If the color value of every pixel were stored, the memory cards of modern cameras with a resolution of ten megapixels or more would soon be full. In the JPEG format, the image data isn’t stored pixel...
by pixel. Instead, it is compressed with the help of computer algorithms with only acceptable information loss in the process. The researchers in Peter Benner’s department develop mathematical methods to compress numerical models, so to speak.

To calculate the glyphosate drift, Benner and Mena had to introduce only a few simplifications to make the model manageable. They selected a zone 13 kilometers long, 10 kilometers wide and 200 meters deep in the border area. They then divided the zone into innumerable cells using the classical finite element method and began to calculate.

TOO MANY UNCERTAINTIES HINDER CONCLUSIONS

The dimensions chosen were based on the real dimensions of a model region. The researchers first calculated the drift in only one air layer and later in the entire quadrant. “The question was whether the entire glyphosate cloud settles within the ten-kilometer stretch leading to the border, or whether it continues to spread out,” Peter Benner explains.

The main problem for the researchers was that they knew very little about the aircraft that sprayed the glyphosate. What was the shape of the spray nozzles? How large were the droplets? In what formulation was the glyphosate sprayed? How fast did the aircraft fly? At what altitude? In what weather? Because they were unable to answer these questions, Mena and Benner relied on estimates and published data. Consequently, they were unable to answer the original question unambiguously. “The quality of the result depends crucially on our ability to model the peripheral conditions,” Benner stresses.

Theoretically, certain guidelines should be followed when spraying glyphosate. For example, the aircraft should take off only if the wind speed, air humidity and temperature are low. They should fly no higher than 25 meters above the ground and should produce the largest droplets possible so that the herbicide cloud doesn’t drift widely. It’s questionable whether these precautions were actually observed along the Colombia-Ecuador border.

“The altitude of 25 meters is completely unrealistic,” says Hermann Mena. The high trees in the Amazon rainforest and the mountainous topography prevent the pilots from flying low. According to Ecuadorian reports, the aircraft actually flew at an altitude of 80 to 100 meters above the ground. Colombia claimed they flew at an altitude of 30 to 40 meters.

GLYPHOSATE DRIFT ACROSS THE BORDER IS POSSIBLE

For the researchers, the political conflict necessitated a fine balancing act. Both sides tried to influence the results. “We endeavored to be as objective as possible,” says Hermann Mena. Together with Peter Benner and René Schneider of Technische Universität Chemnitz, he summarized the results in a recently published book, which draws no conclusion as to whether or not glyphosate drifted across the border.

The scientists merely investigated various scenarios and concluded that it is possible for the sprayed herbicide to have drifted to the Ecuadorian side un-
der certain conditions, for example if the aircraft flew too high, the droplets were too large, the temperature and humidity were too high or the wind was too strong. “The reader can decide what conclusions should be drawn from the scenarios,” says Mena.

Despite this rather vague outcome, the study was an important step forward for Ecuador. With the 203,026.80 dollars the government earmarked for the project, Hermann Mena built a powerful computer center for simulations at EPN Quito. “It was the first basic research project in Ecuador to be financed by the government,” he says. Peter Benner also regards the project as a success: “It greatly improved the standing of science and particularly applied mathematics in Ecuador.” Politicians and industrialists now know that they can turn to mathematicians at the country’s own universities to solve problems.

In September 2013, Ecuador withdrew its lawsuit in the International Court of Justice because the evidence wouldn’t stand up in court. Nevertheless, Colombia has promised to pay 15 million dollars in compensation to Ecuador. Hermann Mena doesn’t believe that Colombia will dare spray the herbicide so carelessly near the border again. In that sense, the conflict, which also drew on scientific arguments, was worthwhile: “The pilots will be much more cautious. That’s a huge success for the people there.”

**TO THE POINT**
- Ecuador brought legal action against its neighbor Colombia in the International Court of Justice because of aerial spraying of the herbicide glyphosate.
- Scientists were asked to calculate the drift of glyphosate in the border region using methods from applied mathematics.
- Because of the multitude of parameters involved, the researchers were unable to provide an unambiguous answer. However, the project indirectly promoted scientific development in Ecuador.

**GLOSSARY**

**Glyphosate:** Discovered in 1950 by Swiss chemist Henri Martin, glyphosate is a chemical compound belonging to the family of phosphonates. The herbicide has been in use for more than 30 years to kill weeds. In comparison with other herbicides, glyphosate generally has lower mobility, shorter persistence in the environment and lower toxicity for animals – properties that are desirable for agricultural use.

**Plan Colombia:** The program was launched in September 1999 and was described by the Colombian President Andrés Pastrana as a “plan for peace, prosperity and rejuvenation of the state.” It called for the deployment of the army for policing duties. Plan Colombia was motivated by the war on drugs, and aerial spraying of coca plantations was an important element of the project. However, the spraying led to environmental damage and health damage, particularly to inhabitants of the affected regions.
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Healthy citizens in a strong nation” – this was the motto espoused by communist Vietnam as it followed in the footsteps of its larger neighbor, China, more than 25 years ago on its way to implementing a socialist market economy. Much has happened in the single-party state since it embarked on the path to reform in 1986. As part of the restructuring measures aimed at establishing a market economy, private trade – previously stigmatized as unproductive or selfish – is now not only permitted, but actively promoted. “But this doesn’t hold true for everyone,” notes Kirsten Endres from the Max Planck Institute for Social Anthropology in Halle. She and her research group, “Traders, Markets, and the State in Vietnam,” have been studying the impact of socio-economic transformation on Vietnamese marketplaces since 2010 and have observed that many of the steps leading from socialism to a market economy entail a tricky balancing act.

MODERNITY COMES TO HANOI

“There’s not as much theft as before,” reminisces the fruit vendor selling pineapple chunks on little skewers to passersby on the roadside in Hanoi. Now she rather fears the police raids, given that the Hanoi People’s Committee has tightened its legislative measures against street vending in recent years. The official reason cited by the city authorities for this decision is the need to bring order to the streets, and to improve food hygiene and safety. For social anthropologist Kirsten Endres, however, this reasoning is a mere pretext. “The street vendors with their wooden shoulder poles or handcarts don’t fit the image of a modern Asian city,” she explains. Those caught plying their trade in certain streets within the metropolis have their goods and utensils confiscated. This isn’t exactly what Endres would call “wealth for all” as proclaimed by the Party. As a result of this policy of displacement, particularly those at the bottom end of the urban economy are deprived of their means of earning a living. “This also holds true for many of the traders selling their wares in the old indoor markets in the inner-city districts,” says Endres. It’s processes like these that make markets an interesting field of research, not only for economists, but also for social anthropologists like Kirsten Endres and her team. “The fact

Waiting for market customers is easy in the comfort of a perfectly-sized space within the fabric storage system.
the state decided to go one step further in its market development policy and approve an ambitious master plan that envisages the modernization of public markets throughout the country. By 2030, the old market halls will be renovated, refurbished or simply torn down and replaced with modern supermarkets, retail centers and shopping malls. “Private investors are explicitly being encouraged to put their money into the new markets,” says Endres. The program has seen large swaths of state-owned real estate in downtown Hanoi privatized or converted into joint ventures. Less than ten years ago, there were only a handful of supermarkets in the entire country – in Saigon and Hanoi – where predominantly foreigners shopped for mainly imported goods. Local residents, in contrast, bought their fresh fruit, meat and vegetables from the traditional markets that could be found in every district. Many of them have since disappeared. They have been replaced by stores with a more contemporary feel, and not only in Hanoi. Each of the country’s more than 60 provincial capitals now has at least one supermarket; shopping malls are springing up in the big cities, and international retail chains are tapping into this new growth market. “All in all, there are about 20 shopping malls and 110 supermarkets in Hanoi today,” reports Lisa Barthelmes, a member of the research group whose dissertation project examines, among other aspects, how the state urges citizens to adapt to its visions, policies and laws.

TRADERS MAKE WAY FOR PRIVATE SHOPPING MALLS

The “Hang Da Market” in Hanoi’s old quarter is one of the markets that have been converted from state-managed to

SUPERMARKETS TOUT IMPORTED GOODS

Stallholders who ply their wares in the city’s many small markets need not fear the police. Their businesses operate on a legal footing, though this apparently doesn’t prevent them from being forced off of their pitches. This is possible because the traders don’t own their market stalls – they have merely leased them from the state for a certain period of time. All this went well until
Within the space of two years, a five-story shopping mall with an area of some 17,500 square meters appeared in its place and now operates under the name of “Hang Da Galleria.” Lisa Barthelmes was there when it opened two years ago. “A great many local residents and curious onlookers came to watch the spectacle,” she says, describing the crowded scenes on the first day. The long-established traders obviously didn’t suit the shiny new look of the place, which is why they were banished to the basement. As Barthelmes learned from one of the women selling vegetables there, the traders must now pay the equivalent of about 80 euros a month to rent their stalls and cover service charges – far more than in the old market. This is a bad deal for them, given that their earnings have literally gone through the floor. Owing to a lack of customers, the vegetable vendor is left with her perishable goods at the end of the day, as are most of the others. As Endres herself noticed, “The market vendors are difficult to find and to access down there. The customers stay away because it’s much more convenient for them to buy from the street vendors who have set up shop next to the mall.”

PURCHASING POWER ALONE DOESN’T FILL STORES

However, things didn’t work out for the investors, either. When the researcher went back to Hang Da Galleria a year later to see what had become of the ambitious plans, she found the shopping paradise deserted. “On the first floor, all I could see were abandoned stores and naked mannequins standing forlornly in the corner,” she says, describing the dreary emptiness that pervaded the building just 12 months after the pomp and splendor of the opening ceremony. The second-hand clothes market on the ground floor, which had already been in the old “Hang Da Market” prior to refurbishment, was the only place where she came across a few customers. “The stores upstairs had to close because nobody wanted to shop there,” was the answer she received when she inquired with one of the female stallholders.

For Barthelmes, it is beyond dispute that the “Hang Da Galleria” is a failed investment. She cites several planning errors as the reasons for the failure. For instance, the planners’ ideas of how urban markets would develop were based on the premise that the consumer behavior of the urban population would change, which evidently didn’t occur to that extent. Although the economic conditions are in place for their assumption to hold true, purchasing power alone can’t fill a shopping mall. Even though continuous growth rates of between 5 and 10 percent in gross domestic product over the past ten years have facilitated the emergence of a well-off middle class that, according to studies, strongly values consumption and consumer goods as expressions of personal wealth, the goods sold in the malls are evidently too expensive for most people. “Even Hanoi’s middle class apparently isn’t willing to spend 100 euros on a pair of Birkenstock sandals,” says Barthelmes, explaining the absence of customers in the new shopping malls.

That’s what the planners get for completely ignoring the shopping culture of Hanoi’s population, adds the research group leader. “In a country where people drive to the market stall on their scooter and make their purchases without even getting off the saddle, it should come as no surprise to anyone that customers won’t frequent any market hall that has
been banished to the basement of a shopping center,” says Endres, joking that “drive-in malls would probably fare better.”

**FROM SLEEPY VILLAGE TO COMMERCIAL CENTER**

The village of Ninh Hiep in the Red River Delta, in contrast, is an example of successful market restructuring. Unlike in Hanoi, where traditional marketplaces have to make way for supermarkets and shopping centers, here, private investors built two new market halls within the hamlet. The village residents have been specializing in trading for many generations and highly welcomed the new market buildings. “The demand was commensurate,” remarks Esther Horat. The doctoral student is studying the life of small-scale traders in Ninh Hiep, whose businesses in fabrics and textiles from China and clothing made of Chinese fabrics have been booming for some ten years now. The once sleepy village has turned into an important hub in the Vietnamese textile trade. “The two new market halls not only satisfied the increased need for vending space, but also boosted the prestige of the traders,” she explains. As Esther Horat’s research revealed, the lucrative business in Ninh Hiep is a real family affair. Among the 4,000 or so family enterprises operating in this trade, there is a strict division of responsibilities. “Some are in charge of importing, others do the cutting or sewing, and then there are others who sell the clothing at the local markets,” she says, reporting on the specialization among players in this market segment. Even the import business is done through social networks. “If you’re not in the loop, you don’t stand a chance,” is her impression. On one occasion, when she accompanied the importers from Ninh Hiep on a buying trip to China, she had the opportunity to observe how important it is to be well connected: “There was a really young trader from Hanoi with us, and he knew none of the Chinese wholesalers, nor was he able to find a translator,” she recalls. “At the end of the day, he went back home empty-handed.”

**CHEAP IMPORTS FLOOD THE BORDERLANDS**

At her own field site, Kirsten Endres has also observed the ways in which social networks operate at the market and through market exchanges. Since the start of her research project a good three years ago, the social anthropologist has, on frequent occasions, spent
several months at a time in the provincial capital of Lao Cai in northern Vietnam, directly on the border to China. There, too, the central market, which has more than 700 registered traders and is the province’s largest, has blossomed into a bustling hub of trade in the wake of the reforms and the normalization of the not-always-peaceful relationship between Vietnam and China. Today, it not only supplies the needs of the population in the region and the surrounding mountainous areas, but also attracts scores of tourists. The market is made up of different sections, separated along category lines, and sells everything the modern world of commerce has to offer. “From cell phones to wide-screen televisions to rice cookers, you really can find everything here,” says Endres, describing what is for sale in the market’s electrical goods department.

Most of the merchandise is imported from China and consists of mass-produced goods of inferior quality. This is not only a cause for concern for the authorities – it is also viewed critically by the traders themselves. “They are aware that the huge quantities of cheap Chinese merchandise flowing across the border day by day, by legal or illegal means, cause harm to the local economy, because Vietnamese manufacturers are unable to keep pace with the low-cost competition,” notes Endres. On the other hand, they also see the social benefits. “They say that this enables even poor people to afford things they wouldn’t be able to pay for otherwise.”

A middleman who Endres met on her visits to the borderlands explained what is characteristic of the business relationships between Vietnamese traders and wholesalers and retailers in the Chinese town of Hekou. “My main capital is the trust I have built up with my Chinese trading partners,” he told Endres. With reference to the economic circumstances behind this interdependent relationship, Endres points out: “What is also important to know is that, like elsewhere in Southeast Asia, small-scale businesspeople in Vietnam buy their merchandise from the suppliers on credit. That’s because it’s difficult to get bank loans. Payment is either made on an agreed date or when the goods have sold at market.”

Business between Vietnam’s small-scale vendors and China’s wholesalers works – but not always smoothly. For instance, the social anthropologist would often hear Chinese traders in Hekou complaining about the payment habits of the Vietnamese. They claim that they often don’t get the money from the Vietnamese market traders on time. “With few exceptions, the Vietnamese come up with all sorts of excuses and reasons why they are unable to pay their debts at this particular moment,” is what one Chinese middleman told Endres. One of the wholesalers is even harder on his clientele: “They don’t even pay when they have the money in their pocket. They simply don’t value trust in business relationships,” he claims. The Vietnamese traders, in turn, criticize what they perceive as a heartless and cold business attitude of their Chinese partners. “The Chinese are pretty darn clever,” she was told by one of the ladies selling souvenirs. “They’re friendly when they sniff a chance to make a profit, but when they don’t, they immediately turn their backs on you.”

PRICE DUMPING UNDERMINES SOLIDARITY

Statements like these exemplify that, for the Vietnamese market traders, it’s not just about mere business. What also counts, according to the researcher, are intangible values like social empathy and solidarity. Talking to the female market traders, she was assured from all sides that it was very important to act as a group, to protect and support each other. And on her long walks around the market, she did indeed observe neighboring stallholders appearing to be very friendly with each other. “When there is nothing going on, the women sometimes sit together and pluck the first grays out of each other’s hair,” she says, describ-
ing the scenes of social intimacy. But as soon as a customer appears, the sense of community is forgotten. “In the many hours I spent at the market in Lao Cai, I witnessed a great many altercations between the women traders,” she recalls. Mostly the arguments came about because one of the others had ruined the business for all of them with her price dumping. “The prevailing ideology of solidarity serves here at most to prevent the biggest excesses in the competitive struggle,” believes Endres.

CORRUPTION OR “MAKING LAW”

Nevertheless, despite the everyday competition in which the market vendors engage, and which is exacerbated by the fact that the merchandise on offer is pretty much identical at each of the different stalls within a given section, they stick together – particularly when they are called upon to shield themselves from third parties, especially the state. Taxes, legislation and trade restrictions cause traders to close ranks as a kind of automatic reflex. Most market traders attempt to make money by walking the fine line between legality and illegality, frequently evading all sorts of taxes, customs duties and even import bans. “Oftentimes, legal regulations are subverted by informal practices,” says Endres, describing the legal subculture that has built up between market traders and local authority representatives, market management and customs officials. This is even reflected in language usage. “They call it ‘making law’,” explains Endres, translating the metaphor that “is nothing more than a euphemistic description of corrupt relations with customs officials and representatives of the market control department.”

To get around the existing legal framework that attempts to regulate the flow of merchandise across the border from China by means of import restrictions and customs duties, the traders negotiate special rules with local state officials. In return for a small contribution, the officials would temper law with mercy. “If we stick to the law, we starve,” is a quote Endres has often heard in justification of the practice. Getting around the restrictions by “making law” not only enables the traders to feed their families, but also allows them to offer their customers favorable prices so that they, too, can access the goods of an affluent society. Seen from this perspective, the “business” of corruption comes across as a pure act of charity. By accepting the money, the official not only shows personal empathy, but also contributes to the public good. “As such, this form of corruption takes on a moral character for all involved and is thus considered a legitimate practice,” says Endres.
But when the law becomes a matter of negotiation in the market, it ultimately turns out to be a bad deal for the small-scale traders. While it may enable them to survive financially, at the end of the day it also keeps them in their precarious situation. “That’s because they are left at the whims and mercy of local officials who, time and again, use the prevailing laws as a pretext for raiding their market stalls and creating a precedent,” says Endres. On more than one occasion, she witnessed the police suddenly turning up at the market to search for smuggled goods or banned imports – which they invariably find, as expected. “It even happened to traders who had bought immunity from such inspections by paying bribes.” Against this backdrop, the social anthropologist takes a critical view of the complicity between the market traders and the authorities, based on alleged empathy and sentiment, as a mechanism for retaining power. “Here we have the paradoxical situation that one partner of the deal is both the perpetrator who engages in the social reproduction of corruption, and the actual victim of the practice,” she explains. While one party in this scheme becomes richer and richer, the other remains in a state of dependency and economic uncertainty. Last but not least, this legal subculture also challenges the successful implementation of the Party’s reform agenda. As Endres puts it: “This practice also exacerbates the existing social inequalities that a socialist market economy should actually be leveling out.”

TO THE POINT

- Traditional meat, fruit and vegetable markets are disappearing, more and more supermarkets are springing up, and shopping malls are opening in the big cities. But in Hanoi, at least, much of what the shopping centers offer doesn’t correspond to the purchasing power and shopping culture of the local population, while in smaller towns and villages, market restructurings are met with acceptance.
- In rural areas, cheap imports from China dominate the markets. For a Vietnamese trader who wants to do business with Chinese wholesalers, it is vital – not least because of the language barrier – to rely on social and/or family networks. The village of Ninh Hiep, for example, has established itself as a major hub of the textile trade, where almost 4,000 families share the workload: they import, they cut, they sew or they sell.
- Lao Cai, provincial capital and trading center at Vietnam’s northern border with China, is a perfect example of the web of social relations, political structures and power struggles: Vietnamese traders depend on Chinese wholesalers to buy goods on credit before selling them, in the face of stiff competition, in their own country. The traders get around import restrictions and evade customs duties by bribing local officials, who nonetheless demonstrate their power by conducting raids. Existing social inequalities are exacerbated.
Inside the Fly’s Onboard Computer

The brain of a housefly weighs around one-thousandth of a gram. Nonetheless, thanks to this miniscule control center, the insect can evaluate images in fractions of a second and steer its way through lightning-fast flight maneuvers. It was Werner Reichardt, Founding Director of the Max Planck Institute for Biological Cybernetics in Tübingen, who, more than 50 years ago, described how the motion detectors in the fly brain work.

The hunting of flying insects appears to give wing to inventions. On the website of the German Patent and Trade Mark Office, the search term ‘fly swatter’ yields six patents, including one model specifically designed “for killing insects on the ceiling,” and another in which a built-in mini vacuum cleaner means that “dead flies are easily collected without additional process stages.”

However, even the most ingenious technology doesn’t guarantee a successful hunt, as the reactive capacity of this particular prey is nothing short of astonishing. Werner Reichardt at the Max Planck Institute for Biological Cybernetics in Tübingen studied how these nimble insects register movements and transform them into course control signals.

Reichardt was born in Berlin in 1924. While still at school, he spent some of his free afternoons working as a lab assistant in the private laboratory of Hans Erich Hollmann, the developer of ultra-shortwave technology. Working on his own, the young researcher also familiarized himself with Maxwell’s theory of electromagnetic waves and thus became an expert on the subject. This expertise was almost his undoing.

Due to his skills in this field, Reichardt was conscripted by the Luftwaffe to work as a radio measurement technician during the war. He met committed opponents of the National Socialist regime in one of the development labs and joined the resistance. He used his expertise to establish a secret radio connection with the Western Allies. Toward the end of the war, the resistance group was discovered. Reichardt was imprisoned and sentenced to death. During an aerial attack on Berlin, he managed to escape with a few of his fellow prisoners.

After the war, Werner Reichardt studied physics at the Technische Universität Berlin and completed his doctorate at the Fritz Haber Institute of the Max Planck Society. As his career progressed, however, biology became the increasing focus of his attention. A key factor in this development was the influence of zoologist Bernhard Hassenstein, whom Reichardt got to know in a detachment during the war, and who aroused his interest in biological questions. The pair decided at the time that, if they survived the war, they would establish a joint research program.

In 1950, the two scientists put their plan into action. Hassenstein was working as an assistant to Erich von Holst at the Max Planck Institute for Behavioral Physiology in Wilhelmshaven, and had told Reichardt about his experiments on the visual motion perception of the weevil or snout beetle Chlorophanus viridis. Reichardt realized that the small green weevil was particularly suitable for the development of a general model on visual motion perception.

Like all insects, Chlorophanus sees the world through compound eyes. These consist of hundreds of individual eyes, each of which perceives a small detail of the environment. The brain then computes the numerous individual shots into a comprehensive mosaic image. But how does the insect perceive movements and the direction of movements?

Werner Reichardt approached this question from the perspective of an engineer trying to work out how an unfamiliar machine works. Based on the experiments carried out on the weevil, he concluded how the structures that trigger a certain behavior in response to external stimuli must look.

The experimental setup was as ingenious as it was simple: “The laboratory animal’s carapace is glued to a small piece of card-
The weevil as a guinea pig: A simple experiment investigates the motion perception of Chlorophanus viridis with the help of the Y-maze globe.

board that is held by tweezers. In this situation, an object made of straw, the Y-maze globe, is presented to the insect, which it grasps voluntarily: “This Y-maze globe was a round object made of six curved pieces of straw arranged in such a way that three of them intersect at four points and form Y-shaped junctions.

When the weevil made walking motions, the straw globe rotated under its feet. It appears that this gave the insect the impression that it was walking upside down along a branch. And, as would probably occur if it were walking through branches, after a few steps, the weevil kept encountering a junction at which it had to decide which direction to take.

The insect usually opts to go right and left with equal frequency. However, this changed when the researchers fixed their test participant in the middle of a rotating hollow cylinder on which vertical black and white stripes were painted. When the striped carousel turned to the right around the insect, it tended to choose the same direction. The strength of this innate optomotor response could be influenced by varying the width of the stripes and the speed of rotation. With the help of numerous experiments, the researchers were able to quantify the optomotor turning behavior of the weevil. Their results formed the basis for a theoretical model describing the principle behind the functioning of the elementary motion detectors in insects.

According to this model, a moving object generates differences in brightness, which are registered by the photosensitive cells in the insect’s compound eye. A motion detector consists of two such cells that receive these light stimuli in sequence and transmit their information to a shared switching point. This postsynaptic neuron compares the interval between the two stimuli, and the brain calculates the direction from this information. Similar to the way in which two light barriers can be used to determine the direction a human went, this is how the insect brain registers motion.

Hassenstein and Reichardt published their model in 1956 in a paper with the rather unwieldy title: Systemtheoretische Analyse der Zeit-, Reihenfolgen- und Vorzeichenauwertung bei der Bewegungserfassung des Rüsselkäfers Chlorophanus [A systems theory analysis of time, sequence and sign evaluation in the motion perception of the weevil Chlorophanus]. Two years later, together with electronics expert Hans Wenking, they were appointed Directors of the Cybernetics research group at the Max Planck Institute for Biology in Tübingen. This group went on to form the nucleus of the Max Planck Institute for Biological Cybernetics, which was established in 1968. Bernhard Hassenstein moved to Freiburg in 1960, and Werner Reichardt carried on working in Tübingen until his retirement in 1992. He died the same year.

At the new institute in Tübingen, the common housefly Musca domestica took the place of the weevil in the striped carousel. Not only was the housefly extremely fertile and easy to keep, its outstanding flying skills meant that it proved to be a very rewarding research object. Using tiny waxed discs, the researchers fixed their six-legged test subjects in the middle of their flight simulators so that the insects would beat their wings without moving. This enabled the scientists to record the reactions of the fly to different visual stimuli under controlled conditions.

Through numerous experiments, Werner Reichardt and his colleagues revealed fascinating details about visual motion perception, such as how the insect manages to distinguish between figures and background and steer directly toward objects. Based on this, the scientists in Tübingen established important foundations for the understanding of higher visual functions. They also succeeded in penetrating further into the fly’s cockpit at the cellular level. For example, using very sensitive measurement probes, Martin Egelhaaf and other researchers from the group examined which neurons are active when the insect reacts to certain visual stimuli.

But the precise appearance of the motion detectors described by Reichardt and Hassenstein remained a mystery. Were they the cells that the famous Spanish neuroanatomist Santiago Ramón y Cajal had discovered as early as 1915 and described as “curious elements with two tufts”? For over 50 years, this question was something like the Holy Grail of fly research.

The tufted cells are far too small for their electrical signals to be extrapolated using measurement probes. The mystery remained unsolved until the scientists had special fluorescent proteins available to them that light up when the cell is active. Alexander Borst, Director at the Max Planck Institute of Neurobiology in Martinsried, and his colleagues made the tufted cells of the fruit fly Drosophila visible with the help of such proteins and measured their activity. It actually emerged from their tests that the mysterious cells were, in fact, the elementary motion detectors described by Werner Reichardt and Bernhard Hassenstein in 1956.

Moreover, many years ago, French researchers developed a “fly robot” that perceives motion based on the principle proposed by Reichardt and Hassenstein. Using its electronic compound eyes, the fly robot maneuvers through a labyrinth on three wheels. “However, the machine cannot fly and is capable of only comparatively pathetic movements,” noted the Frankfurter Allgemeine Zeitung in 1994. The skills of its much smaller winged model remain unequalled to the present day.
Cooperation with JAPAN

The Max Planck Society has 104 cooperation projects with scientists in Japan; 198 Japanese researchers visited a Max Planck Institute in Germany as a guest in 2013. In addition, the Max Planck Society has enjoyed close ties with Japan’s leading research organization RIKEN for 30 years through a joint research agreement. RIKEN was founded in 1917, based on the model of the Kaiser Wilhelm Society.

All of this is reason enough to introduce some of the successes of this German-Japanese cooperation in a small, special edition of our research magazine. Cooperation projects with Max Planck can be found all over Japan, for example in Tokyo, Nagoya, Okazaki and Fukuoka. Topics range from astronomy, materials research and neuroscience to chemical ecology. And the collaboration is currently being further expanded in the form of two Max Planck Centers: the Max Planck RIKEN Center for Systems Chemical Biology and the Max Planck – The University of Tokyo Center for Integrative Inflammology.
Sugar Chains and Smoker’s Cough

For the last three years, packages containing sugar molecules have regularly made their way from Germany to the Japanese city of Wako, north of Tokyo. The sender is Peter H. Seeberger’s department at the Max Planck Institute of Colloids and Interfaces, and the addressee is Naoyuki Taniguchi at the RIKEN Advanced Science Institute.

The scientists have been pooling their expertise at the RIKEN Max Planck Joint Research Center for Systems Chemical Biology since 2011. “The center combines the power of automated sugar synthesis developed at Max Planck with the medical expertise of the physicians at RIKEN to allow fundamental insights into a devastating disease that would be impossible for each institution by itself,” says Peter H. Seeberger, Director at the Max Planck Institute in Potsdam. While the scientists in Germany specialize in the synthesis of complex sugars and have gathered a large collection of different chemical compounds, their colleagues in Japan are experts in the field of glycobiology and conduct research into the role of sugar chains in disease, among other things. “Almost everyone at our end is a chemist. We can produce first-rate molecules, but then we need a group that’s more focused on biology to test their function,” explains Daniel Varón Silva of the Max Planck Institute of Colloids and Interfaces.

The fact is, our body is teeming with proteins that have sugar chains attached to them. In some cases, there might be just a few molecules, while other times there is more sugar than protein. These glycoproteins, to use the technical term, are important components of cell membranes and also function as signal molecules. When signalling pathways are disturbed, it frequently leads to disease. This is why glycoproteins have long been the focus of Naoyuki Taniguchi’s research team.

**GLYCOPROTEINS INVOLVED IN SMOKER’S LUNG**

In one of his projects, the Japanese scientist is studying the onset of emphysema. Also known colloquially as smoker’s lung, this condition is a chronic obstructive pulmonary disease (COPD). Cigarette smoke and other airborne pollutants damage the cell membrane of the tiny air sacs, or alveoli, where gas exchange takes place. The tissue disintegrates, the alveoli become large pockets, and soon the air can no longer be exhaled. The used, low-oxygen air is trapped in the lung and the patient is plagued by a wet cough and life-threatening shortness of breath.

Some three million people around the world die every year from COPD, making it the third leading cause of death, according to the World Health Organization. Although lifelong smokers bear an especially high risk of COPD, only one in five actually suffer this fate, indicating that some individuals are better protected from it by their genetic disposition.

A team headed by Naoyuki Taniguchi recently discovered that a gene called Fut8 plays an important role in the onset of emphysema. Fut8 is responsible for attaching fucose sugar molecules to glycoproteins, thereby changing their function. Mice with less Fut8 developed emphysema after just three months of exposure to cigarette smoke, while mice with normal Fut8 levels displayed the symptoms only after six months.

Blood tests on former smokers corroborate these results. People with lower Fut8 activity exhibited a worse lung condition and suffered more intense COPD episodes than those with raised Fut8 levels. This protein may lend itself as a biomarker to predict the course of the disease in individual patients.

In a new project together with Bernd Lepenies from the Max Planck Institute, Taniguchi hopes to discover which immune receptors detect the sugar molecule during COPD. “We have created a library of possible receptors and are now searching for the right candidate,” explains Lepenies.
Micro-computed X-ray tomography of lung emphysema (yellow) in mice. To study the disease, scientists developed a mouse model in which the chemical elastase triggers emphysema-like lung disease. Mice treated with elastase and exposed to the bacterial cell wall component lipopolysaccharide show accelerated progression of the disease (bottom) compared with animals exposed only to saline solution (top).
Successful Hunt for Exoplanets

German and Japanese astronomers at the Subaru telescope scrutinize the immediate neighborhood of distant stars

With a mirror diameter of 8.2 meters, the Subaru telescope is one of the largest individual telescopes in the world. The National Astronomical Observatory of Japan (NAOJ) operates this giant eye on the summit of the extinct Mauna Kea volcano in Hawaii. Researchers from the Heidelberg Max Planck Institute are part of a cooperation that allows them to participate in observation programs here – rather successfully, as it turns out.

The German and Japanese scientists are working together in the SEEDS project (Strategic Explorations of Exoplanets and Disks with Subaru). The data required here is provided by the HiCIAO high-contrast camera and the IRCS infrared camera, among others. The Japanese and German teams working on the SEEDS survey are led by Motohide Tamura and Thomas Henning, respectively. Recently, the group again studied a distant planetary system and obtained infrared images of the Jupiter-like object known as GJ 504b.
These portraits are the first of a celestial body that orbits a Sun-like star – GJ 504, which is around 60 light-years away in the Virgo constellation. The distance between the planet and its parent star is 44 times Earth’s average distance from the Sun, around 6 billion kilometers. Researchers estimate its mass to be around three Jupiter masses. This means that GJ 504b would also be the lightest of all the exoplanets photographed to date, and certainly the coldest.

Almost all of the more than 1,000 exoplanets known at present were detected only indirectly: either by their gravitational effect on their host stars or because they regularly shade out a tiny fraction of the light from this star. Although direct images are rare, they are extremely useful. They provide indications of temperature and some atmospheric properties of the planets observed, among other things.

It is very difficult to image exoplanets directly. The glare of the stars hides their planets – typical intensity ratios are one to a billion or more. This would be like trying to take a photograph of a dust particle orbiting a 100-watt light bulb at a distance of 8 centimeters while standing 80 kilometers away.

The only way to make the planets visible at all in such images is by employing sophisticated technical tricks. These include methods that block the light of the star by mechanical means (coronography) as well as analytical methods that combine several images of the planetary system under investigation in precisely the right way to suppress image interferences.

The SEEDS project, which recently passed its halfway mark, has provided more than just impressive images of GJ 504b. The scientists have also photographed disks of gas and dust surrounding young stars from which the planets of these stars are formed.

The Max Planck Institute for Astronomy is one of the founding members of SEEDS. “The researchers of our Star and Planet Formation Department have a wealth of experience in terms of observation strategies, image processing of the high-contrast images necessary for direct imaging, and modeling of the physical properties of exoplanets,” says Max Planck Director Thomas Henning. “We were therefore an obvious partner for SEEDS – and we are absolutely delighted that so much progress has been made in recent years!”

Data Carpet in a Memory Chip

Scratchproof polymer coatings pave the way for organic data storage devices of the future

In the future, organic coatings could be used in memory chips in order to make the components printable and low cost. Researchers in Rüdiger Berger’s group at the Max Planck Institute for Polymer Research in Mainz have teamed up with partners at the University in Tohoku, among others, to develop surfaces with scratchproof coatings from a redoxactive polymer. The electrical resistance of these polymer coatings can be changed specifically in tiny areas with the aid of a very sharp, conducting tip. Data bits can thus be stored in the coating and read again many hours later. These properties make them promising candidates for future organic data storage devices. However, the writing and reading process can abrade the polymers over time. The Mainz-based scientists have therefore undertaken a further project to make the polymer coatings even more robust. They couple the chain molecules to a surface in such a way that they line up next to each other like the fibers of a carpet. The storage density in such a data carpet is around one terabit per square inch, which corresponds to the content of more than four DVDs on one square centimeter.

By chain elongation to a data carpet: Based on the results of the cooperation with Tohoku University, Max Planck researchers grew polymer chains on a substrate via a technique called surface initiated atomic transfer radical polymerization (SI-ATRP). The resulting polymer carpets might be useful for solar cells or organic memory devices.
Birth of a Star in the Radio Telescope

German and Japanese astronomers observe filaments in molecular clouds

The birth of stars is a complex process: Large molecular clouds initially contract into elongated thin filaments. Inside these filaments, the smaller cores of molecular clouds form, and these clouds eventually give birth to one or more stars. Jochen Tackenberg and Henrik Beuther from the Max Planck Institute for Astronomy in Heidelberg observed how the gas in these filaments moves. They recorded radiation emitted at a wavelength of three millimeters from rotational transitions of the diazenyl ions (N$_2$H$^+$). Since these ions occur only in relatively dense regions, and moreover are destroyed during the course of the subsequent star formation, they are ideal for visualizing the early collapse phase and the filaments in particular. But only a sufficiently large radio telescope shows the details. Tackenberg, Beuther and colleagues therefore teamed up with Takeshi Sakai from the University of Electro-Communications in Tokyo. The researchers used the 45-meter Nobeyama radio telescope in the “Japanese Alps” on Honshu to investigate around 16 large molecular filaments in greater detail. The images clearly show how gas flows along elongated filaments toward the cores of molecular clouds.

Brain Responses to Negation

In Japanese and German, the same brain areas are responsible for similar language processes

Japanese and German could hardly be any more different. They belong to separate language families and differ in phonetics, grammar and sentence structure. Nevertheless, the brain processes many aspects of these elements similarly. Scientists from the National Institute for Physiological Sciences in Okazaki, Japan, in collaboration with the Max Planck Institute for Cognition and Neurosciences in Leipzig, Germany, found out that the same linguistic processes can even activate the same brain areas in both languages. In experiments using functional magnetic resonance imaging, the researchers tested Japanese sentences using the special marker しか (‘shika’). These sentences require two constraints. First, they must include a negative marker, ない (‘nai’), corresponding to “not” in English, e.g. すべてしか歌を歌わない (‘Anybody other than Peter does not sing songs’ or “Only Peter sings songs”). Secondly, the ‘shika’ marker generates a focus interpretation, similar to “only” in English, e.g. “Only Peter sings songs.” By including other Japanese sentences with ‘shika’, the scientists discovered that the left inferior frontal gyrus is responsible for the syntactic process required by ‘shika’. In addition, a focused phrase in Japanese activates a semantic network that comprises the left frontal cortex and the angular gyrus in the left temporo-parietal cortex. These results are comparable to findings in German indicating that the same brain areas are recruited when similar underlying processes take place, despite other important differences between Japanese and German.

Whereas the left inferior frontal gyrus (IFG) is responsible for complex negations in Japanese and German, a focused phrase relies on neuronal activity in the frontal cortex (FC) and the angular gyrus (AG).
Captive Breeding Has Impaired Olfactory Functions in Silkmoths

Domesticated silkmoths have a much more limited perception of environmental odors compared with their wild relatives.

The silkmoth *Bombyx mori*, originally native to China, was domesticated about 5,000 years ago. Its larvae, silkworms, enclose themselves in a cocoon when they enter the pupa phase. They spin their cocoon from one single silk thread, which is several hundred meters long. For silk production, the cocoon — together with the pupa inside — is boiled and the silk filament is then unravelled. Special breeding moths are kept for silk farming. After mating, female moths lay several hundred eggs from which the new silkworms hatch.

Scientists from the Max Planck Institute for Chemical Ecology and their collaborators from Japan have found that domesticated silkmoths are now considerably impaired in their olfactory functions due to captive breeding. The moth's perception of environmental odors, which may lead it to its exclusive host plant, the mulberry tree, has been significantly reduced. This was demonstrated when their responses to odor stimulation were compared with those of the closely related wild species *Bombyx mandarina*. The scientists recorded electroantennograms of individuals of both species that were stimulated with different scents from leaves or flowers. Morphological analysis revealed that the number of sensilla on the antennae of the domesticated females is considerably reduced compared with the abundant sensilla of their wild relatives.

In addition, the researchers measured different activity patterns in the brain of the domesticated and the wild silkmoths by using calcium imaging techniques. These patterns were highly variable among individuals of domesticated silkmoths, but were largely constant in their wild ancestor group as well as in four other insect species.

In the domesticated species, the number of sensilla is considerably reduced (left) in comparison with its closely related wild ancestor (right).

Aromatic, with a Filling

Cyclic molecules loaded with other substances self-organize to form components for solar cells and nanowires.

Some substances have a strong desire to arrange themselves in an orderly way. Large aromatic molecules that resemble disks and rings cut from chicken wire stack up of their own accord in columns on a suitable substrate. A collaboration including scientists from the Max Planck Institute for Polymer Research and Tokyo Metropolitan University, among others, is using this principle of self-organization to produce nanostructures for electronic components. They use aromatic hydrocarbon rings, for example, into whose center they pack graphene, dye molecules or metal ions. The stacks that grow in this way could serve as components for photovoltaic cells or the starting material for custom-made nanowires, depending on their filling. In order to identify the best hybrid materials to use here, the cooperation partners test the physical properties of nanostructures made of different components and investigate the charge transport through the stack or their photovoltaic qualities, for example.
From Tip to Base

Differences in growth factor receptor turnover underlie the maturation of sprouting blood vessels

During development and regeneration, new blood vessels are rapidly formed to provide nutrients and oxygen to the new tissue. To this end, endothelial cells at the edge of the growing vessel network must react sensitively and quickly to cues in the environment. Vascular endothelial growth factor (VEGF), for example, acts as a signpost that guides growing vessels in the right direction. Endothelial cells at the tips of vessel sprouts rapidly internalize VEGF receptors, thus changing the receptors’ signaling properties. In contrast, cells in previously established, more mature vessels bear fewer VEGF receptors and form a more stable network. According to scientists from the University of Nagoya, the City University of Yokohama, Japan, and the Max Planck Institute for Molecular Biomedicine in Münster, Germany, the regulation of surface receptor endocytosis might underlie the transition of VEGF-sensitive sprouts into mature vessels. The researchers discovered that, in the developing mouse retina, endothelial cells at the tips of the vessels rapidly take up VEGF and internalize VEGF receptors. In established vessels, however, the enzyme atypical protein kinase C inhibits this process. The scientists found that the active form of this enzyme was abundant in maturing endothelial tubes, but absent from sprouts. Atypical protein kinase C thus promotes the transition of endothelial sprouts into mature vessels.

Delving into Cracks

A detailed understanding of how cracks form in hydrogenated steels helps in the development of more robust materials

Using hydrogen on a large scale as a fuel is a challenge – and not just for the energy sector, but for materials scientists, too. This is because the tiny hydrogen atoms can easily penetrate into the steels of tanks or pipelines, for example, and cause the material to become brittle. Researchers at the Max-Planck-Institut für Eisenforschung GmbH, the National Institute for Materials Science in Ibaraki, and Kyushu University in Fukuoka are investigating where exactly cracks develop in hydrogenated steels and the role the gas plays in this process. The research has shown that the first hairline cracks open up not only at the boundaries between the microscopic crystal grains that make up the alloys, as occurs in hydrogen-free steels. They also form within the grains, at very well-matched crystal boundaries, known as twin positions of the atoms, which previously were not thought to be susceptible to crack formation. As soon as the researchers understand this hydrogen embrittlement in detail, they want to develop materials that exhibit better resistance.
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