New Energy through Chemistry
Scientists are tapping into alternative resources

FOCUS

QUANTUM OPTICS
Training Atoms

DEVELOPMENTAL BIOLOGY
How Light Gets on the Nerves

CRIMINAL LAW
Experiments in Temptation

METEOROLOGY
Climate Memory
More quality of life due to Personalized Medicine

Every person is different – also genetically. That’s why we are placing our faith in Personalized Medicine: Our Pharma and Diagnostics divisions are working together on tests and active agents to better tailor therapies to the needs of our patients. Our innovations help millions of people by alleviating their suffering and improving their quality of life. We give them hope.

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More Effects.
Fewer Side.
Seating of Learning

To paraphrase Gertrude Stein, a sofa is a sofa is a sofa is a sofa. However, this example in the library of the Max Planck Institute for Social Law and Social Policy in Munich has connotations that extend beyond the Wikipedia definition of “a piece of upholstered furniture suitable for sitting or reclining.” The designer objet dating from the late 1960s came to prominence thanks to the persistent myth that Jürgen Habermas had sat on it, steeped in thought. Starting in 1971, he joined Carl Friedrich Weizsäcker as Director at the Max Planck Institute for the Study of Living Conditions in the Scientific and Technical World in Starnberg. Nine years later, upon Weizsäcker’s retirement, the institute was renamed the Max Planck Institute for Social Sciences and relocated to Munich. The sofa and Habermas moved with it.

Soon after, however, the sofa acquired a new owner with the arrival of Franz Emanuel Weinert. Habermas took his leave, and Weinert remained, becoming the Founding Director of the new Max Planck Institute for Psychological Research. This also no longer exists: in 2006, it was merged with the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig.

Only the sofa still remains. Perhaps because it is “tainted with odium,” as Emeritus Wolfgang Prinz put it, without so much as a hint of disrespect. “Institutes come and go, but the sofa survives,” says sociologist Gertrud Nunner-Winkler with a smile. For well over 30 years, her career and that of the sofa have progressed in parallel, as both made the transition from Starnberg to Munich. Whose seat of learning is it now? Library users like to sit on the sofa as they leaf through books and journals. It’s a very comfortable place indeed to seek out information.
New Energy through Chemistry

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There is a surplus of carbon dioxide on Earth – and not necessarily to the advantage of the environment. Chemists, on the other hand, want to make a virtue of necessity and use carbon dioxide as a chemical raw material, which would keep the greenhouse gas out of the atmosphere.

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Almost nothing happens in chemistry without catalysts. But the reaction accelerators have one disadvantage: they often contain – sometimes rare – metals that need large amounts of energy to do their job. But maybe it is possible to do without them?

ON THE COVER: These xylose crystals, imaged under polarized light, resemble an abstract painting. Xylose is also known as wood sugar, and is released in depolymerization processes. In these experiments, researchers are looking for chemical compounds that can be used as energy sources and raw materials.

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The larvae of the ragworm possess the simplest eyes in the world. This makes the animal a perfect model organism for studying, for instance, how sensory stimuli are relayed.

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In German hospitals alone, 30,000 patients die every year from antibiotic-resistant infections. Researchers are aiming to outwit these bacteria with the help of specially coated dressings and implants.

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A drop of water or a microorganism is made up of countless atoms that escape our everyday experience. Nevertheless, researchers are using single atoms to study the interaction between light and matter.
Society, the economy and science have a burning problem: Women must finally be enabled to play an appropriate role in leading positions. As long as women continue to have less favorable opportunities than men, we are squandering valuable potential. But what is the right way to go about this? How can we reach a situation in which women are adequately represented at the management level – also at the Max Planck Society?

There is still a gap between men and women in science as they climb the career ladder: While there are more female graduates than male, at the doctoral level, the ratio is around 45:55 in favor of men. Among post docs and in W2 posts, women account for barely 30 percent. The share of female professors is around 25 percent. And at the W3 level, fewer than 10 percent of post holders are women – a sobering thought. But where do the causes lie?

Allow me to highlight three factors that make it difficult for women to pursue a scientific career: the lack of compatibility between family and profession, the insecurity of scientific career planning – due mainly to short-term contracts – and the fact that the majority of male scientists frequently have too little regard for their female counterparts.

Life is particularly difficult for female scientists with children. Childcare facilities remain a rarity. We in the world of science are not alone in facing this problem, but the effects on us are particularly serious, as female scientists can’t afford to step aside from their profession for an extended period – science is advancing at too fast a pace. At the Max Planck Society, we try to be particularly supportive of employees with families. We have substantially increased the availability of childcare: 47 of our institutes now have cooperation agreements in place with external nursery operators, and 6 more will follow. Since 2006, we have invited the Hertie Foundation to carry out its audit berufundfamilie – career and family audit – as another means of promoting a family-friendly human resource policy. The resulting certification provides female applicants with a transparent picture of our goals and the steps we are taking. But we are dependent on political will: The Max Planck Society can merely try to secure nursery places for its employees. As a rule, we are reliant on the existence of widespread, well-developed childcare facilities.

The uncertainty of career planning, on the other hand, is a phenomenon that is intrinsic to the world of science. A scientific career can’t run along the same lines as a career in civil service. Young scientists need to gather experience abroad and familiarize themselves with a variety of institutions. Therefore, a certain proportion of scientific posts must be of a fixed-term nature – not just here in Germany, but in other important research nations, as well. And this affects not only women, but men, too. On the other hand, we should beware that women are not awarded fixed-term contracts more frequently than men. And we must open up new career paths, for example by increasing the emphasis on tenure-track appointments. The prospect of a fixed probationary period leading to a permanent management post reduces the inherent uncertainty.
The third cause is particularly tricky. Studies show that male scientists generally give preference to men. This is due mainly to subconscious role model perceptions. At the same time, a current survey by the Center for Higher Education confirms that the proportion of female scientists in the highest positions has risen by 1 percent each year. For example, from 1997 to 2008, the ratio of female senior faculty members rose from 17 to 27 percent. Nevertheless, it is striking that, even in disciplines in which women are traditionally well represented, such as the social and life sciences, the proportion of women still doesn’t exceed one in three.

In general, it appears difficult to raise the percentage of women in top positions above this mark – even outside the world of science and in an environment that is particularly supportive of women. Figures recently released for the Federal Ministries in Berlin have clearly made the point: even at the Federal Ministry for Families, no more than 29.4 percent of secretaries of state, heads of department and sub-department managers are female.

A glimpse at the big picture shows that the Max Planck Society’s targets are realistic. Compared with other German research organizations, we are doing well. But we can’t be satisfied with a situation in which women account for less than 9 percent of our Directors. For this reason, at its meeting in March, the Senate adopted a self-imposed commitment to increase the number of female scientists in management positions. Within the next five years, we intend to increase the share of women in TVöD pay groups E13 to E15U, as well as in W2 and W3 posts collectively by one percentage point per year; by 2017 we expect one third of these TVöD posts and one quarter of W2/W3 posts to be held by women. We already gained positive experience with such a commitment between 2005 and 2010.

At first glance, the target may seem rather unspectacular, but it must be taken into account that fluctuation over a five-year period is limited. Directors’ posts, in particular, are occupied on a long-term basis, meaning that we can only gradually increase the proportion of women. Moreover, in absolute figures, five or even eight percentage points constitute remarkable growth. The increase in female W2 and W3 post holders between 2005 and 2010 had the concrete effect of more than doubling the number of female scientists at this level. Overall, we succeeded in raising the number of women in these posts by 53 percent. The result was to noticeably heighten the representation of female scientists in positions of responsibility at our institutes. The new commitment we have undertaken now aims to raise the number of female Directors by a further 60 percent, and to increase the number of female research group leaders (W2) and female scientists in management positions in TVöD employment by around 20 percent.

We simply can’t afford to squander the gifts of outstanding female scientists. Especially at the Max Planck Society, we need exceptional talent – and we need creative women who are able to think outside the box.

\[\text{We intend to raise the number of female Directors by a further 60 percent}\]

PETER GRUSS
President of the Max Planck Society
A Test for Risk-Takers

Scientists at the Max Planck Institute for Human Development present a new tool to assess risk competence

How well do we understand the risks that we face in our day-to-day lives? Are we able to correctly assess statistical information and the pros and cons of important decisions – for example, when investing money or considering radical medical treatment? Scientists at the Max Planck Institute for Human Development in Berlin, in cooperation with Michigan Technological University and the University of Granada, have now developed the "Berlin Numeracy Test." Their studies show that this test is twice as accurate in predicting risk competence as other commonly used tests.

The "Berlin Numeracy Test" is a cogent new instrument that rapidly delivers a valid prognosis of an individual’s ability to comprehend statistics and risks. In 21 studies involving more than 5,000 participants from 15 countries, the scientists have shown their numeracy test to be the most powerful indicator to date in identifying the ability to understand numerous day-to-day risks (for example in connection with medical diagnoses and drug treatments) or statistical probabilities (such as weather forecasts). It has proven to be twice as meaningful as widespread cognitive tests.

This easy-to-use tool is available to all interested parties at www.riskliteracy.org.

New Partnership in Fusion Research

The Max Planck Society is intensifying its commitment to the development of sustainable energy supplies with the foundation of the Max Planck Princeton Research Center for Plasma Physics

On March 29, 2012, on the campus of Princeton University, Princeton President Shirley M. Tilghman and the President of the Max Planck Society, Peter Gruss, jointly signed the agreement to set up the new Center. "Particularly in the field of fusion research, it is essential that we pool our strengths, as well as our knowledge," President Gruss emphasized, "if, in the coming years, we want to develop nuclear fusion to provide what the world so urgently needs: a safe, clean and dependable energy technology."

The Max Planck Institute for Plasma Physics in Garching and Greifswald (IPP) is partnering with the Princeton Plasma Physics Laboratory (PPPL) in the field of fusion research. In the field of astrophysical plasmas, the Max Planck Institutes for Solar System Research (Katlenburg-Lindau) and Astrophysics (Garching) will be working together with the Faculty of Astrophysics at Princeton University. “The goal of this joint venture is to make greater use of the synergies between fusion research and the work of our astrophysicists,” said Sillye Günter, Director at the IPP. The results of the joint investigations into fusion and astrophysical plasmas will be used to develop theoretical models, furthering the study of fusion power and its practical application as an energy source.
“We need to explain the benefits of transgenic animals”

Guy Reeves on genetically modified insects

For some years now, genetically modified insects have been released into the environment in various countries across the world. The laboratory creatures are intended to prevent their counterparts in the wild from multiplying, as a means of combating infectious diseases and agricultural pests. Guy Reeves of the Max Planck Institute for Evolutionary Biology in Plön has been taking a close look at these transgenic animal release trials.

What sort of genetically modified insects have been released into the environment so far?

Guy Reeves: In the US, there have been releases of transgenic pink bollworms — a species of moth that causes great damage to cotton plantations — since 2005. And transgenic male yellow fever mosquitoes, a species that can also carry dengue fever, have been released in Malaysia, Brazil and on the Cayman Islands since 2009. All of these creatures were either infertile or equipped with a suicide gene that resulted in the bulk of the larvae dying. When these creatures mate with their counterparts in the wild, the numbers of offspring with the ability to survive are low and the mosquito population declines. The mosquitoes from the laboratory can’t reproduce in the long term and automatically die out.

What uses do such creatures have?

Transgenic insects can be a weapon in the fight against infectious diseases, particularly those for which there is still no vaccine available, such as dengue fever. In agriculture, the technology can be used to combat certain pests, so farmers have less need for pesticides. On the other hand, no results have yet been published showing whether transgenic creatures are more powerful in decimating natural populations than the infertile irradiated mosquitoes that have been released worldwide for some 60 years now. So we don’t yet know whether this technology is more effective than the traditional radiation method.

There is much talk in the media about “Frankenstein mosquitoes.” How would you answer the question of whether genetically modified insects can sting?

Yes, it’s possible — people really could be stung by transgenic mosquitoes. The idea is to release exclusively males, which, in contrast to the females, don’t feed on blood. But the technology is not one hundred percent reliable, so about 0.5 percent of the millions of mosquitoes released are female. What’s more, the transgenic creatures are not entirely infertile as claimed — between 2 and 4 percent of their offspring survive. Given that millions of such mosquitoes have already been released in populated areas, it must be assumed that there are some genetically modified females among them. It is unknown whether the sting of a transgenic mosquito can have consequences in terms of health.

Why are such issues not clarified before transgenic insects are released?

I suspect that it is in order to avoid controversy. Although a lot of scientists who, like me, work in this field do consider this to be extremely short-sighted. It’s alarming that the world’s first release trial involving transgenic insects took place in one of the few countries in the world with no laws on this issue — on the Cayman Islands. Then again, this technology is relatively low-risk.

What is the legal situation in the European Union?

The EU is currently revising its guidelines. During the course of this year, the European Commission will be initiating a public consultation on the release of genetically modified insects. Citizens, companies and organizations with an interest in this issue or who have specialist knowledge will be able to participate in drafting regulations. I would hope that a broad cross-section of the public will take part in the discussion. The British government is currently looking at an application from British company Oxitec to release transgenic cabbage moths in Great Britain. It can’t be ruled out that this trial may take place before the new EU rules are in place. It’s still a little early to make predictions, but there are encouraging signs that future release trials involving transgenic insects will be carried out on a scientifically sound and transparent basis in the EU.

Following the release of genetically modified mosquitoes on the Cayman Islands, some of the local population felt that they had been taken advantage of as guinea pigs to try out new technology. Do you understand their concerns?

In view of the poor information policy, this impression is hardly surprising. I would probably feel the same way myself — particularly since the population of the Cayman Islands has thus far had no lasting benefit from the trials.

Why is it so important that the local population be made fully aware in advance of a release trial?

People will accept this technology only if they precisely explain the benefits and risks of transgenic insects to those directly concerned. If we fail to do so, the technology itself is doomed to failure. You mustn’t forget that you can refuse a drug or a vaccine — but when genetically modified insects are released in your neighborhood, you can’t get away from them.

Interview: Harald Rösch
Europe’s Courts under Pressure to Reform

The European Court of Justice is facing huge challenges – a study by the Max Planck Institute for Private Law in Hamburg reveals the reasons and offers potential solutions.

Whether you’re buying a car, booking a holiday or considering credit, there are few transactions nowadays to which the law of the European Union does not extend. Not just cross-border transactions, but also internal domestic legal relationships are subject to a host of directives and regulations that define the rights of consumers and businesses. The decision as to which party prevails in a dispute is increasingly dependent on the European Court of Justice (ECJ) in Luxembourg, which guarantees the enforcement of European law within the EU.

However, the ECJ is faced with great challenges: “With the dramatic increase in caseload, the extended time needed for cases to be heard, as well as a significant extension to its mandate, the European Court of Justice is reaching the limits of its capacity in some areas,” says Hannes Rösler, a staff member at the Max Planck Institute for Private Law in Hamburg. For example, since the first case was referred in 1961, the number of preliminary rulings has increased from 1 to 385 in 2010. At the same time, the number of petitions to all three EU courts in 2010 climbed to 1,406 – “the highest number in the history of the Court. With the exception of the European Court of Human Rights, the Court of Justice has the highest workload of all international courts,” Rösler continues. The average of 17 months to hear each case also presents problems. “With the time taken by national courts as well, it is not unusual for a case in Germany to last four years or even longer,” Rösler calculates. Which is too long, say the critics.

According to Hannes Rösler, the only way out of the mire is through reform. A form of judicial federalism must be developed between member states and the European courts. Above all, structural reform needs to be implemented to create a new European judicial architecture. In turn, this would require the Court of Justice to develop specialization in the relevant disciplines. Moreover, European justice must be more approachable for ordinary citizens, to enable them within certain limits – in a departure from the past – to appeal directly to the Court of Justice. The long-term goal in Rösler’s view should be a new, codified system of European procedural law and conflict-of-law rules that will make it simpler to bring cases to trial before foreign courts and the ECJ.

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Research on the Move

The new iPhone app offers up-to-date reports, podcasts and videos, as well as an interactive timeline on the history of the Max Planck Society and the Kaiser Wilhelm Society.

The arrival of the MaxPlanckApp heralds a new information channel that combines the topicality of the website with the principle of mobility. “Whether you’re on a train or in a café, if you’re interested in the research being carried out at Max Planck institutes, you can now download current reports directly onto your phone, and even check the location of an institute via Google Maps,” says Christina Beck, who heads the Department of Press and Public Relations. Such apps are particularly popular with school and university students who have forsaken traditional Internet access via PCs and laptops in favor of smartphones. All of the articles can be quickly forwarded to friends via e-mail.
More Prizes for the Competition “Jugend forscht”

Starting in 2012, the Max Planck Society is donating all of the physics prizes from the regional level up to the national competition

The junior research competition “Jugend forscht” began in 1965. This broad-based initiative to encourage junior researchers was launched by Stern magazine editor-in-chief Henri Nannen with the declared aim of “finding the researchers of tomorrow.” The model was borrowed from the US, where science fairs have a long tradition. Young people come to the fair to present their research projects and inventions to a broad audience, as well as to an expert jury that decides on the awards. Nannen quickly found some willing partners for the German initiative. Several companies agreed to sponsor the competitions in individual states. The Max Planck Society has been involved as a prize donor since the 1970s – and recently agreed to fund all five biology prizes at the national level. This year, just under 6,000 projects came up for inspection by the jury and the public. More than 10,000 budding scientists took part in Germany’s most famous junior research contest in 2012. The national finals were held this year from May 17 to 20 in Erfurt.

“Jugend forscht” is often a team effort – those who make it to the finals will already have triumphed over their rivals at the regional and state level.

Horizons in Molecular Biology
Registration for the 9th “Horizons in Molecular Biology” international PhD student symposium is now open. This year, students will bring together 23 speakers – among them Nobel laureate Kurt Wüthrich, synthetic biologist Drew Endy and ribozyme specialist Ronald Breaker – talking about very different areas of research, from RNA structure to viral evolution, from synapses to plant stomata. At the preceding career fair, students can gain insights into career opportunities outside of academia. The symposium will take place from October 8th to 11th 2012 in Göttingen, Germany.

www.horizons.uni-goettingen.de

Justice in Conflict
Few YouTube videos have gone viral quite as dramatically as “Kony 2012,” which has been viewed almost 100 million times. It marked the start of a campaign aimed at bringing Ugandan war criminal Joseph Kony to justice. Patrick Wegner, a doctoral student at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg, spent three months conducting research in Uganda in 2011. In his blog “Justice in Conflict,” he gives a detailed description of human rights breaches in crisis regions, as well as taking a critical look at the rights (and wrongs) of the Kony 2012 campaign.

www.justiceinconflict.org/author/patrickwegner

Ripples in Space
Albert Einstein predicted their existence in the last century, but held their discovery to be impossible. However, that hasn’t stopped astronomers like Karsten Danzmann from looking for them: gravitational waves. Scientists in Hanover are using the GEO 600 detector to track down the rippling waves. So far, they haven’t succeeded. But their work – on the frontiers of modern physics – is nevertheless exciting. The latest Max Planck German-language film takes a look over their shoulders and graphically explains the significance of these ripples in space-time, and why they might one day open up a new perspective on the cosmos.

www.mpg.de/5598262/gravitational_waves
The terms systems biology and synthetic biology are currently experiencing a boom – something that has already occurred several times in the history of biology. But what do they actually signify in scientific terms? Are they an expression of a far-reaching change within the discipline, or mere promotional buzzwords that simply “fill old wine into new bottles” in order to present it in a more palatable form? An analysis.

TEXT HANS-JÖRG RHEINBERGER

OP THE CLAIM OF REPRESENTING SOMETHING AKIN TO AN EXPERIMENT-BASED GENERAL BIOLOGY, A CLAIM THAT IT SUCCEEDED IN ASSERTING. GENETICS ASKED THE BASIC QUESTIONS OF LIFE, INsofar as this was possible using experimental means. In addition, it introduced to biology the practice of working with model organisms, and established a kind of experimentation that is more or less the distinguishing feature of the field of biology – the crossing experiment as carried out by Gregor Mendel in the mid-19th century.}

This experimental revolution was accompanied by a conceptual shift. In 1909, the term “gene” was introduced by Wilhelm Johannsen, who also was the first to differentiate between gene and characteristic, that is, between genotype and phenotype. This distinction proved to have far-reaching consequences: it established a hierarchy for organisms based on interior and exterior, center and periphery, essence and appearance. The accompanying trend for gene-centered thinking would leave its mark on the life sciences throughout the 20th century.

The relationship between gene and characteristic enabled the investigation of fundamental questions regarding the manifestations of life. However, the experimental processes available to classical genetics at the time didn’t enable scientists to explain what genes consist of and, above all, how they influence the expression of characteristics.

Genetics asks the basic questions about life

The terms systems biology and synthetic biology are experiencing an inflationary boom in the context of the life sciences. Not only are they being appropriated by research programs, databases, institutes and companies, but increasing numbers of scientists are also using them to describe their work. However, as a look back at the history of biology shows, there is nothing at all new about this phenomenon. Genetics became established as a special discipline within the field of biology in the early 20th century. In reality, it was more than that. It went on to develop the claim of representing something akin to an experiment-based general biology, a claim that it succeeded in asserting. Genetics asked the basic questions of life, insofar as this was possible using experimental means. In addition, it introduced to biology the practice of working with model organisms, and established a kind of experimentation that is more or less the distinguishing feature of the field of biology – the crossing experiment as carried out by Gregor Mendel in the mid-19th century.

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Network map of a cell: Every biological system consists of a nested network of smaller reaction pathways. Without such complex interconnections, life could not function.
Both of these questions were successfully tackled by molecular genetics, which emerged around the mid-20th century. What occurred at this point was more of a rupture than a seamless transition from classical to molecular genetics. In the course of this molecular biology revolution, a new generation of biophysicists, biochemists and biologists identified nucleic acids as the genetic material, and understood gene expression as a translation of genetic information into biological function.

The subsequent development of molecular genetics into molecular genomics had two further consequences: on the one hand, it pulverized the oversimplified “gene for” concept of classical and early molecular genetics, and, on the other, it led to the emergence of genetic engineering and genome analysis. Genetic engineering and genome analysis, in turn, established a new form of molecular cell biology, which provided a hitherto inconceivable abundance of applications. This new field was developed and refined from the 1970s to the early years of the new millennium without the scientific community deeming it necessary to introduce new names for it.

This situation changed around the turn of the millennium, at the time of the successful completion of the human genome project and the failure of a first wave of gene therapy experiments in medicine. Since then, a profusion of new names for the next stage have been in circulation, many of which are derived from the term genomics: we hear talk of transcriptomics, proteomics, metabolomics, and even organomics.

But two terms stand out from all others: systems biology and synthetic biology. Both terms have gained enormous popularity within a very short period and can be found gracing not only daily newspapers, but also scientific journals, including a specialist publication that incorporates both terms in its title: *Systems and Synthetic Biology*.

What the two terms have in common is that, first, the new associated terminology, which would be comparable to that originating in the periods of classical genetics and molecular genetics and could be viewed as the harbinger of a new era, is not clearly identifiable. Second, they are terms that have already been in vogue at various stages in the history of biology.

The term “system” signified different things at various stages in the history of the life sciences. The natural history of the 18th century was shaped and driven by a concept of system as an ordering category for the diversity of life forms. Linné’s *Systema naturae* is representative of this trend.

This changed in the late 18th century. Once the term biology was coined and an independent experimental biological science appeared on the scene, the dividing line between physics, chemistry and biology repeatedly ignited the debate as to how organisms could be analyzed without losing sight of life itself. It could even be claimed, perhaps, that the associated new system concept – in the form of a whole that is greater than the sum of its parts – actually launched the idea of biology as a science in the first place. Immanuel Kant referred to living organisms as “organized and self-organizing beings.”

In the late 19th century, a debate between development mechanics, on the one hand, and more systemically oriented biologists, on the other, triggered a renewed debate on developmental biology. The theoretical work carried out in the systems biology of the early 20th century focused on concepts like steady state and field. However, its proponents remained outsiders, for the most part; as theorists, they were very much peripheral to experimental biology.

In the 1950s and 1960s, biological cybernetics shifted the focus in biology from the molecular level to behavior, to systems-based thinking. In its wake, molecular biologist and Nobel laureate Fran-
François Jacob proposed the general concept of the integron for the hierarchy of the feedback loops to which organisms are subjected. Interestingly, simultaneous to the emergence of genetic engineering in the 1970s and the sequencing boom of the 1980s and 1990s, the term cybernetics slowly but surely disappeared from the biological literature, and concepts like the integron were hardly adopted at all.

So what characterizes the current increasingly forceful call for a systems biology? Sydney Brenner, who was awarded the 2002 Nobel Prize for his research on the genetic regulation of organ development in the roundworm *Caenorhabditis elegans*, views it as nothing more than an empty buzzword. “Systems biology is not a science,” he stated categorically in a recent interview. He expressed the view that the important new insights in the life sciences will continue to be gained through the tried and tested analytical modus of molecular biology.

A new generation of life scientists clearly takes a different view. However, clarification is urgently required as to precisely what constitutes the systemic character of contemporary systems biology. Has the focus on the genetic level of organisms come to an end? Are there new concepts that extend or even replace the repertoire of molecular biology – genetic program, structural gene and regulator gene? It appears that concepts like that of the network, which is widely disseminated in the sciences today, are far too general to assume such a role.

Or is the use of the term systems biology justified by new laboratory and computer technologies? Today, high-throughput technologies like DNA and protein chips and the new generation of sequencing processes produce vast volumes of data on cellular processes. In this context, however, the term “system” is more an expression that refers to the immense volumes of data that are generated in the laboratories with the help of chips and robots and that can no longer be evaluated without the help of computer programs.

What would be referred to here is thus primarily a technical system – namely one involving the organization of the biologists’ work and, therefore, a parallel world of data production and processing – and less so the characteristics of the organism, the actual object of this work. If this were to be the case, the question would arise, of course, as to how the two worlds relate to each other. Unfortunately, those involved are making little or no effort to establish clarity on such issues.

This brings us to synthetic biology. Once Louis Pasteur’s view that organisms arise only from existing seeds and do not spontaneously appear on Earth became established during the course of the 19th century, biology focused on the question as to how organic life could arise on Earth throughout the 20th century. To the present day, however, the corresponding syntheses have been merely fragmentary. And the current concept of synthetic biology relates only to the periphery of these approaches.

Scientists repeatedly referred to synthetic biology over the course of the 20th century, initially in conjunction with synthetic chemistry. The aim of this discipline was not only to recreate organic substances from existing elements in the laboratory, but also to generate substances that don’t occur in nature in this form.

The term was also used occasionally in connection with the initial successes of genetic engineering in the 1970s. However, it did not become widely established at the time. Instead, the terms genetic technology and genetic engineering took hold and went on to dominate the public debate for three decades.

The boom in the use of the terms synthetic biology and systems biology began only with the start of the new millennium. Here, too, we must question...
whether this is merely a swapping of labels that is not scientifically motivated, and constitutes an attempt to steer public perception in a new direction. Or has there been a qualitative leap in the concepts and techniques for the manipulation of life as compared with the 20th century that would justify the adoption of a new name?

The use of the term is vague. Today, the experiments by American researcher Craig Venter come under the term synthetic biology. Venter tries to recreate entire bacterial genomes artificially and wants to use them to replace a natural genome. The term also covers the experiments carried out to define a minimal bacterial genome that would just suffice to enable a bacterium to reproduce.

Synthetic biology also includes the permanent incorporation of biological-chemical subsystems into organisms that provide the latter with new characteristics. In addition, the use of modified nucleic acids as genetic material and the attempts to change the genetic code are also considered to be synthetic biology.

But don’t all of these cases merely involve the application or further development of technologies that, until ten years ago, were referred to as genetic engineering or, more generally, biotechnology? What is the reason for this new self description?

Two scenarios are conceivable. The first and more controversial of the two would be that the soft concept of synthesis is used today to encourage a more positive attitude to the deliberate and permanent modification of living organisms, and involves the adoption of a new linguistic label in response to the widespread skepticism toward genetic engineering with a view to attracting new funding.

The other scenario is that the life sciences actually are undergoing a transition on a scale that is eclipsing molecular biology and the recombinant DNA technologies of the last century, and heralding a new era of biological evolution controlled by people.

If this is the case, Darwin will ultimately be overtaken by his own analogy. As is generally known, he based his theory of natural evolution on the model of artificial selection familiar to him from the breeders of his time. Today, we may well be facing a situation in which the breeders (“designers”) of our time are really getting down to business. However, this would require an entirely different debate.

**The Author**

Hans-Jörg Rheinberger, born in 1946, is a Director at the Max Planck Institute for the History of Science in Berlin. His work deals primarily with the changes to which the issues and experimental approaches in biology have been subjected over time. A native of Liechtenstein, he studied biology and philosophy in Tübingen and Berlin, and is a member of the Berlin-Brandenburg Academy of Sciences and the German Academy of Sciences Leopoldina.

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The new linguistic label responds to the general skepticism
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Climate Protection in a Nanosponge

Recycling for waste gases: Researchers at the Fritz Haber Institute hope to stop power stations from pumping carbon dioxide into the atmosphere, where it causes the greenhouse effect. They want to use it to generate fuel or raw materials for the chemical industry.
Three problems, one solution: This is the special charm of a research project on which Malte Behrens and Robert Schlögl are working at the Fritz Haber Institute of the Max Planck Society in Berlin. The chemists want to use carbon dioxide as a chemical raw material, which would keep the greenhouse gas out of the atmosphere, replace coal, gas and oil, and store renewable energy.

TEXT PETER HERGERSBERG

This waste is invisible and quite harmless at normal concentrations. It doesn’t smell bad or attract vermin, and yet it is a rather nasty form of garbage that humanity needs to grapple with: carbon dioxide. Industry, traffic and private households heat the climate with an extra 35 billion tons of the greenhouse gas every year. One possible solution is to dispose of the gas in underground repositories, although this is very controversial. It would be better to recycle the waste that is generated primarily by burning fossil fuels.

In any case, Malte Behrens and Robert Schlögl, together with their colleagues at the Fritz Haber Institute of the Max Planck Society in Berlin, hope to help turn this colorless, odorless gas into a fuel or a raw material for the chemical industry: methanol or carbon monoxide. Other research groups are working to generate methane or formic acid from the greenhouse gas. Whatever the final substance, carbon dioxide is anything but the ideal reactant, as it is relatively inert – there is a good reason why it is used as a fire extinguisher.

Chemical activation of the gas is also the aim of the CO2RECT project in which the Berlin-based scientists are involved. Its name stands for CO$_2$ Reaction using Regenerative Energies and Catalytic Technologies. The project is sponsored by the German Federal Ministry of Research, and involves four major partners in industry and ten academic research institutions, including the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg.

METHANOL AS STORAGE FOR RENEWABLE ENERGY

Using carbon dioxide as a raw material would not only help the climate, but it could also help replace fossil resources. The greenhouse gas could even become a storage medium for chemical energy, advancing the energy transformation. “Unless we solve the storage problem, we won’t be able to make the switch to renewable energy,” says Robert Schlögl, Director at the Fritz Haber Institute. Since the energy provided by wind turbines and solar panels fluctuates with the wind and the sun, supply seldom matches demand.

Power stations that convert fossil fuels into electricity plan to cover the gap by storing wind and solar energy for times of higher demand. One candidate is hydrogen, which can be ob-
station for renewable energy. “The fact is, storing energy in hydrogen is far more difficult and expensive,” says Liisa Rihko-Struckmann.

The Magdeburg-based scientist also considers it reasonable to recycle carbon dioxide as carbon monoxide. Carbon monoxide gas is poisonous and not exactly easy to transport, but it shares an advantage with methanol: it is very useful to the chemical industry, as it lends itself to the synthesis of more complex chemical compounds, including synthetic motor fuel.

METHANOL SYNTHESIS WITH PURE CARBON DIOXIDE

In fact, the industry already converts carbon dioxide to methanol on a very large scale, with some 90 factories around the world producing almost 50 million tons of the alcohol in this way every year. Still, the Berlin-based scientists are concentrating on this very question of methanol synthesis. They want to find out whether the established process actually achieves maximum efficiency, and they also hope to optimize the procedure for obtaining carbon dioxide from waste gases.

The industry currently doesn’t use the carbon dioxide emitted from the chimneys of coal power stations for methanol synthesis. Rather, it works mostly with a gas mixture that is specially produced from natural gas or coal, and that contains a considerable amount of carbon monoxide, as well as hydrogen and carbon dioxide. The established processes aren’t particularly efficient at converting pure carbon dioxide from coal-fired power stations or the like to methanol. This is mainly due to the catalyst that binds the carbon dioxide to the hydrogen – and it is precisely in the area of this chemical matchmaker, without which little would happen in the chemical industry, that Malte Behrens and Robert Schlögl are experts.

“We are searching for the ideal catalyst for converting pure carbon dioxide to methanol,” says Malte Behrens, “and we are doing so using a knowledge-based approach.” In other words, the chemists in Berlin want to start by understanding why the mixture of copper, zinc oxide and a small dose of aluminum oxide, which is currently used to convert the carbon dioxide-carbon monoxide mixture, works so well. Trial and error has shown this recipe to be especially effective, but only when it is prepared according to a very precise procedure. The Max Planck scientists are also investigating why this procedure must be adhered to so strictly.
Based on their findings, Malte Behrens and Robert Schlögl then hope to identify chemical matchmakers that will be the ideal mediators for such reactions as methanol synthesis. “We have deliberately selected the example of an established industry process to show that our strategy is successful,” explains Robert Schlögl. It is an ambitious goal, as the chemical industry has already made many efforts to increase the efficiency of the catalyst for methanol synthesis.

**MODEL SYSTEMS OVERSIMPLIFY CATALYSTS**

However, industrial researchers and developers have not tried what the Berlin scientists propose. “We are convinced that you have to study catalysts in all their complexity,” says Schlögl. To date, chemists have studied the copper-zinc oxide catalyst in simple model systems, such as precisely measured copper islands on a completely smooth zinc oxide surface. The catalyst used in industrial reactors has little to do with this idealized model. The reality is that the reaction mediator used in industry is a sponge-like conglomeration of countless spheres, each measuring ten nanometers (millionths of a millimeter), some of copper and some of zinc oxide, with a small scattering of aluminum oxide.

Until a few years ago, the state of knowledge was that the actual reaction occurred only at the copper spherules. Moreover, chemists long assumed that, to increase the activity of the copper, they need only give it a large surface area – so a sponge of countless nanospheres seemed to be exactly what was called for. For years, textbooks assigned zinc oxide the role of a spacer that pre-
vents the copper particles from fusing with each other in the heat of the reaction, forming larger spheres with a comparatively smaller surface area.

“It has been clear for some time, though, that there’s more to zinc oxide,” explains Malte Behrens, “because other copper systems with a similar structure exhibit hardly any catalytic activity.” So it’s not just a question of a large surface. The role of the aluminum oxide also remains unclear. The literature describes it as a promoter, which effectively means something like: “It helps, but we don’t really know why.”

Malte Behrens and his colleagues are testing many possible catalysts in order to discover why zinc is different from other metals, what factors other than surface area influence the quality of a catalyst, and what part the promoter plays. Sometimes the material mixtures differ in one of their components, and sometimes in a detail of the preparation process, because the procedure holds the key to catalyst research – in both senses. “Many chemists think of the production of industrially relevant solid-state catalysts as a kind of black magic,” says Behrens, who plans to demystify the area.

To show how his team goes about its work, he starts in a laboratory where Julia Neuendorf has already prepared an experiment. On the bench stands an apparatus holding a sealed glass vessel at eye level. Inside the vessel, which is as tall as a forearm and just too wide to close two hands around, a mixer stirs a small amount of water. This is where the precursor of the catalyst will be formed – a finely distributed mixture of copper carbonate and zinc carbonate.

THE CATALYST HAS A CHEMICAL MEMORY

Using a number of probes and tubes, a computer monitors the temperature, conductivity and turbidity of the reactor’s contents, “but the most important thing is the pH,” states Julia Neuendorf. “We have to optimize it for each precursor.” This is because the pH in particular, but also the temperature, influences when the precursor components are precipitated from the solution and what shape their tiny crystals take on, thus also determining the appearance of the final catalyst. “We discovered that the catalyst has a chemical memory,” says Malte Behrens. “So it’s really important to have a good understanding of the precursor.”

On a computer monitor, Julia Neuendorf keeps an eye on all parameters that provide information about what is happening in the semi-automatic precipitation reactor. A pair of colored horizontal lines signals the calm before the experiment. When the doctoral student presses a key, one of the curves falls fast. A blue solution drips into the reactor, and the pH drops into the acid range. The computer immediately triggers the addition of alkaline sodium carbonate and quickly ropes the pH curve in again. At the same time, the solution clouds up with a greenish-blue substance, a mixture of copper carbonate and zinc carbonate.
As soon as the reactor vessel is full, Neuendorf will filter off the precursor, dry it, heat it and then expose it to hydrogen. Copper oxide and zinc oxide are formed at the heating stage, and the hydrogen releases the oxygen from the copper. Ultimately, the catalyst will have exchanged its malachite green color for an unassuming black. Air no longer agrees with it, because the finely distributed copper would immediately react with the oxygen. The Berlin-based chemists thus take care to keep the catalyst protected from the air while they study it using all the resources of modern catalyst research.

To this end, the catalyst makes a stop in the laboratory of Stefan Zander, who feeds the material through different instruments. X-ray diffraction enables him to determine the crystal structure of the nanoparticles and even to see how it changes as the catalyst does its work. He analyzes the chemical composition using X-ray fluorescence spectroscopy, and has something particularly sophisticated ready for surveying the surface of the finely granulated copper: reactive frontal chromatography. This involves a flow of nitrous oxide, better known as laughing gas, through the porous catalyst.

“Laughing gas is a mild oxidizing agent that deposits precisely a fixed amount of oxygen,” explains Stefan Zander. “We capture the nitrogen that is left over.” The amount of nitrogen tells Zander how much oxygen was chemisorbed onto the copper, and thus the size of the copper surface.

A LOOK AT INDIVIDUAL ATOMS REVEALS THE SECRET

But the true test is actually waiting in the wings where Edward Kunkes and Nygil Thomas work. These chemists test the catalyst at a temperature and pressure that would be used in industry. They feed carbon dioxide and hydrogen through the catalyst and analyze what comes out using gas chromatography.

The catalysts studied by Malte Behrens’ team routinely undergo these tests at the Fritz Haber Institute. However, it was a particularly close look at the catalyst that opened his eyes and those of his international colleagues as to why the combination of copper, zinc oxide and aluminum oxide and their tried and tested production process works better than all the alternatives to date. In the images generated by a high-resolution transmission electron microscope, the scientists made out individual copper and zinc atoms in a small section of the aggregate.

The atomic structure revealed that the catalyst performed properly only when defects were present. Small irregularities in the crystal lattice of the copper particles are expressed on the surface as kinks, notches and barbs, and the reactants and intermediate products of methanol synthesis bind particularly well to these very defects, as team members from Stanford University calculated.

The look at the individual atoms in the copper-zinc oxide sponge also confirmed a suggestion that had been made repeatedly in scientific publications on methanol synthesis: zinc oxide is not only present in nanoparticles that act as spacers between the copper particles; it also spreads over part of the copper, forming a disorderly layer just a few atoms thick. Individual zinc atoms probably even finagle their way into the copper lattice.

“As the calculations by our colleagues from Stanford University showed, the oxygenated intermediate products bind better to the zinc atoms than to the copper atoms,” says Malte Behrens. If the catalyst gives the intermediate products a better grip, they are generated more readily. This means

FOCUS New Energy through Chemistry

Job profile of a catalyst for methanol synthesis: In principle, the highest methanol yields are gained by conversion using pure carbon monoxide and hydrogen. The currently used copper-zinc oxide catalyst uses a carbon dioxide-carbon monoxide mixture in the ratio of one to two, but gives very poor yields when pure carbon dioxide is used. The scientists in Berlin are searching for a catalyst that will generate methanol efficiently from pure carbon dioxide at relatively low temperatures, expressed in Kelvin.
that the catalyst works better overall, because its main function is to generate the unstable chemical structures that inevitably result on the path from reactant to product.

“This leads us to believe that the active areas of the catalyst are where the zinc oxide and the copper defects meet.” The team’s findings also shed light on the role of aluminum. The triple-charged aluminum ions probably integrate into the double-charged zinc lattice and change its electronic properties, so that the thin layer of zinc oxide lies more loosely on the copper particles.

Since the researchers now know the exact place where the carbon dioxide and hydrogen bond, they can explain why only the industrially established procedure delivers a workable catalyst. The fact is, it is only under those specific temperature and pH conditions that a catalyst precursor forms from which copper crystals with tiny defects and a thin zinc oxide coating are generated in the subsequent stages of the process.

“Our data would indicate that it may be possible to further optimize the tried and tested copper-zinc oxide system,” says Malte Behrens. “But I think that, to identify considerably better catalysts for methanol synthesis using pure carbon dioxide, we will have to look at new combinations of materials and new synthesis strategies.” Since the scientists in Berlin discovered the secret of the most efficient reaction mediator to date, they know what to look out for.

Even if there’s not much that can be changed in the existing copper-zinc oxide system itself, its production process can be improved – at least in terms of sustainability. In the current industrial procedure, large amounts of nitrates accrue, and these either over-fertilize the water or are processed at considerable expense. “In our experiments with different precursors, however, we found that we can replace the nitrate with ecologically harmless for-mic acid salts,” says Behrens. “This means we can use an environmentally friendly process to generate a catalyst that has the same structure and efficiency as the one that uses the nitrate solution.”

CARBON MONOXIDE PRODUCTION WITHOUT PRECIOUS METALS

One of Behrens’ suggestions for improving the catalyst that converts inert carbon dioxide into active carbon monoxide goes even further. He recently presented a combination of materials consisting of nickel, magnesium oxide and aluminum oxide. His group had previously completed a detailed analysis of the catalysts generally used in industry. They play their part as chemical mediators quite well – but only thanks to a precious metal component such as rhodium or platinum.

Not only does the material from the Berlin-based laboratories manage without expensive precious metals, it may also permit greater efficiency in carbon monoxide production. After all, it retains its nanostructure even at 1,000 degrees, so it could work at very high temperatures. This would be good for efficiency, as carbon dioxide and hydrogen generate more carbon monoxide as the temperature in the reactor rises. Tests to assess how well the
nickel-based catalyst works at high temperatures are still ongoing. If it proves itself, it could soon replace the competition from precious metals.

As promising as this work is, the catalysts used to convert carbon dioxide into workable compounds pose only a problem of greenhouse gas recycling. Scientists laboring to produce hydrogen by electrolysis also face major challenges. This method virtually hands them the fuel for the conversion of carbon dioxide, but delivers satisfactory efficiency only when expensive iridium or ruthenium dioxide electrodes are used.

These expensive precious metal compounds are unsuitable as catalysts for water splitting on a major scale, and thus for the goal of the CO2REACT partners. Malte Behrens’ group has also been working on this issue – and is ready with a possible solution. They discovered that a much cheaper composite material comprising manganese oxide and carbon nanotubes is an alternative to the conventional electrodes.

Robert Schlögl hopes to pursue this more economical replacement in Mülheim an der Ruhr, at the Max Planck Institute for Chemical Energy Conversion that is set to emerge from the Max Planck Institute for Bioinorganic Chemistry. Researchers there will tackle fundamental difficulties that arise in the conversion of renewable energy to storable forms, like methanol, and usable forms, like electricity. This is feasible only with the experience that Robert Schlögl has accumulated in catalyst research, because one thing is clear to him: “The problems of energy conversion and storage are catalyst problems.”

**TO THE POINT**

- Catalysts convert the greenhouse gas carbon dioxide into methanol or carbon monoxide, which can be used as raw materials for the chemical industry or as liquid fuels.
- The chemical exploitation of carbon dioxide makes it possible to protect the climate, store energy from the wind and sun, and create a replacement for fossil fuels.
- The precursor of a catalyst plays a major role in determining its properties and catalytic activity.
- A precise understanding of catalyst preparation and the catalytic processes enables more environmentally friendly production of catalysts for methanol synthesis, as well as a catalyst without precious metals for generating carbon monoxide.

**GLOSSARY**

Semi-automatic precipitation reactor: Uses automatic feedback loops to regulate the conditions, especially temperature and pH, under which salts are precipitated from a solution.

pH value: A negative logarithm of the concentration of oxonium ions (protonated water molecules) in a solution. It provides information on whether a solution is acid or alkaline.

Precursor: A substance created when metal salts are precipitated from a solution. It forms a catalyst after passing through a number of intermediate steps, including aging and recrystallization.
Hunting for Treasure among the Wood Chips

Wood waste and straw contain valuable substances for the chemical industry, and these substances are what chemists from the Max-Planck-Institut für Kohlenforschung in Mülheim an der Ruhr and the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg want to get their hands on. The researchers are looking for ways to convert biomass into useful chemical compounds and use them as energy sources or raw materials.

PETROLEUM

Petroleum isn’t being traded for the price of extra virgin olive oil quite yet, but we know that deposits will soon be running dry. Natural gas and coal won’t last forever, either, and besides, all fossil fuels harm the climate. So it’s high time to give serious thought to finding sustainable and climate-neutral energy sources.

Wind power and solar energy would be ideal for generating electricity and heat, or moving vehicles from A to B. Solar cells covering just part of the area of the Sahara would be sufficient to supply the entire world’s electricity needs. Perfect! Except for one problem: Electricity can’t be turned into skin cream or painkillers. It can’t be molded into computer casings or plastic bottles. And aircraft can’t take off with it. Electric current is nothing more than the directed movement of charge carriers. No material, not a single molecule is involved.

Petroleum, on the other hand, has a lot more to offer than its energy content. It’s also a multipurpose raw material for countless items that make life easier, or simply nicer. This dark, dirty liquid, the result of millions of years of decay of dead marine organisms, is the basis for medicines, cosmetics, plastics, paints and coatings, fertilizers and plant protection products, insulation materials, detergents, and the list goes on.

“Providing an ongoing supply of energy and raw materials to industry is one of the most urgent issues we face over the next 30 years,” says Ferdi Schüth. As a chemist, he’s certain that there can be only two long-term re-
placements. “Biomass, which would allow us to benefit from some of the natural world’s synthetic capability. And C1 building blocks.” Biomass, too, could be broken down into these tiny molecules that contain a single carbon atom. Schüth is in charge of the Heterogeneous Catalysis department at the Max-Planck-Institut für Kohlenforschung in Mülheim an der Ruhr. His team is looking for ways to make efficient use of biomass.

The Earth has no shortage of renewable raw materials. Second-generation bioethanol is no longer produced from plants containing starch or sugar, the cultivation of which competes with food production, but instead from wood waste and straw. Both of these could, however, also be chemically converted into industrial raw materials. Just that proportion of plant waste that is indigestible for humans would probably be enough to meet demand for chemical production.

Put that way, it sounds simple, but it isn’t. This is because the chemical composition of biomass is utterly different from that of petroleum. The latter is a mixture of somewhat uninspiring long-chain, cyclic and aromatic hydrocarbons. It consists almost entirely of carbon and hydrogen. Biomass, in contrast, contains substantially more complex molecules. The main constituents are sugars that are linked together to form starch or cellulose chains, and these have a considerable oxygen content.
Biomass can indeed be converted into carbon monoxide and hydrogen, or “synthesis gas,” from which hydrocarbons and other classes of molecules can then gradually be synthesized. But what a waste of nature’s synthesis skills, which have been refined over millions of years! Targeted disassembly into the building blocks that industry requires would be much subtler ... and more elegant. As Schüth emphasizes, “The past century has seen the development of selective functionalization reactions.” By this, he means that chemists can systematically oxidize molecules, for instance to form alcohols or acids. “The task we face now is how to create an entirely new kind of chemistry, focusing on defunctionalization.” The aim now is, for example, to take sugar molecules that have numerous hydroxyl groups and remove some or all of the alcohol functions. A paradigm shift is under way – exciting times for chemists.

It’s no accident that research for the post-petroleum era is being carried out in the middle of a former coal-mining region. The Kaiser-Wilhelm-Institut für Kohlenforschung, founded back in 1912 and the predecessor of the present Max Planck institute, laid the foundations. Driven by increasing levels of motorization, Franz Fischer and Hans Tropsch developed a large-scale industrial coal liquefaction process here in 1925. In this process, coal was first converted to synthesis gas, the carbon monoxide-hydrogen mixture mentioned above, by partial oxidation at over 1,000 degrees Celsius and gasification with water vapor. In a second reaction, involving catalysis at elevated pressure and temperatures of between 160 and 350 degrees Celsius, liquid hydrocarbons were formed. These are suitable as diesel fuel or a primary material for the chemicals industry.

SALT CAN BE USED TO TURN WOOD INTO SUGAR

This Fischer-Tropsch synthesis was of huge significance in the darkest period of Germany’s history. Under the Third Reich, motor fuel was classed as “essential to the war effort.” By 1945, nine large-scale industrial plants had been built in the former German Reich with a total capacity of 600,000 tons per year to produce synthetic diesel from domestic coal. Production was carried out, in part, with forced labor and in concentration camp outposts.

Due to the unbeatably low price of oil, coal liquefaction was suspended in West Germany after World War II, but saw a first renaissance during the 1970s oil crisis. The great strength of the “Fischer-Tropsch” process is that it can make use of virtually any carbon source, making it highly topical once again. But now the desired feedstock is wood rather than coal. However, Ferdi Schüth and his team also want to use this renewable raw material in an entirely different way.

The main constituent of wood is cellulose, which consists of chains of hundreds to 10,000 glucose molecules. If the bonds between them are broken, the sugar can be fermented into bioethanol. But if this is to be achieved, cellulose must first be dissolved. This is a problem because this biopolymer is virtually insoluble in anything, because the sugar chains are additionally linked together with countless hydrogen bridges.

“In 2002, it was discovered that cellulose is soluble in ionic liquids,” explains Roberto Rinaldi, winner of the Sofia Kovalevskaya Prize awarded by the Alexander von Humboldt Foundation, and independent group leader at the Mülheim-based institute. These are salts whose cations consist of organic molecules. Due to their larger molecular radii, they exhibit only weak cohesion compared with common salt. Accordingly, ionic liquids melt at temperatures as low as less than 100 degrees Celsius, while table salt doesn’t become liquid until it reaches 860 degrees. Once dissolved, cellulose needs an acid as a catalyst in order to snap the bonds between the individual sugar molecules. But how can the salt be removed again? Rinaldi had the clever idea of using an acidic ion exchanger instead of sulfuric acid. Being a granular resin, it can simply be filtered out after the reaction. So, as crazy as it might sound, salt can indeed be used to turn wood into sugar. But price is a vital con-
sideration here. “If we are to make the process cost effective, we can afford to lose virtually none of the ionic liquid in each cycle. This is because, in a continuous process and on a large scale, losing even just one milligram per kilo of sugar is costlier than the alternative grown in a field.” One kilo of beet sugar costs 20 euro cents.

But Rinaldi has another alternative to hand. “Using a ball mill, wood chips mixed with dilute sulfuric acid can be ground down into minuscule particles: oligosaccharides that are just three to six sugars long and dissolve in water.” Brute force combined with acid catalysis – sometimes the best solutions are quite simple.

But there is more to plant biomass than just polysaccharides; there is also lignin. A resinous, disordered network of polymerized aromatics, this substance accounts for 20 to 30 percent of the solids content. It penetrates the cellulose fibers, acting as a kind of support stocking for plant tissue. Its building blocks are highly crosslinked by chemical bonds. Some researchers even believe that a tree’s lignin is a single giant molecule.

LIGNIN – A TREASURE TROVE FOR THE CHEMICALS INDUSTRY

For each liter of bioethanol produced, three kilos of lignin are obtained. “What should we do with it? Break it down into synthesis gas?” Rinaldi shakes his head. “No, we’re trying to come up with something better to do with it.” Its aromatic constituents make it a treasure trove for the chemical industry. This is because these particular hydrocarbons have uses in the production of drugs, polymers and dyes, among other things. Lignin is the only natural source for them. And, globally, around 30 billion tons are formed from scratch each year. That’s quite some potential!

Lignin is easily isolated: wood is converted into fine chips and then boiled under pressure with 50 percent alcohol. Once the solvent is removed, lignin is left behind as a viscous brown mass. If this is heated to 250 to 300 degrees Celsius, it breaks down into its component parts. “But when we do that, it’s virtually an explosion in a pharmacy,” chuckles Ferdi Schüth. Roberto Rinaldi nods in agreement. “That’s right, hundreds of products are obtained, each of them in tiny quantities.” Even using sophisticated methods, the mixture can be separated only to a certain extent. “But the real nightmare is that it immediately repolymerizes!”

A simple route to sugar: A ball mill grinds wood chips with sulfuric acid. Cellulose can also be broken down in this way without using a costly ionic liquid. This creates oligosaccharides that are easy to process.
The Brazilian is phlegmatic, viewing it as a personal challenge. In nature, fungal enzymes break lignin down, but only very, very slowly. Rinaldi is looking for catalysts that can do the job faster and, at the same time, deactivate all those sites on the building blocks where the molecules can reattach themselves to one another. Instead of lignin, he is carrying out tests cleaving small aromatic compounds such as diphenyl ether with nickel. He has found that the efficiency of the reaction varies depending on the solvent used. This is a first small step on the long path to making use of lignin.

Like coal liquefaction, the development of catalysts is permanently associated with this Mülheim-based institute. It was here that the second director, Karl Ziegler, developed organometallic catalysts for manufacturing plastics. In 1953, he filed a patent for a process with which ethylene is catalytically linked to form polyethylene. Building on this foundation, his Italian colleague Giulio Natta then created polypropylene in a similar manner. In 1963, the pair shared the Nobel Prize for Chemistry. Today, Ziegler catalysts are used worldwide to produce more than 70 million tons of plastics annually.

Wolfgang Schmidt is also working on catalysts for biomass conversion – specifically on catalysts that convert synthesis gas, a mixture of carbon monoxide and hydrogen, obtained from plant waste into small, useful basic chemicals. Working together with the Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) in Oberhausen, he is developing a continuous process for producing dimethyl ether (DME). This gaseous compound has many different uses, for instance as an alternative motor fuel, liquefied gas or a diesel additive.

**WANTED: ONE CATALYST FOR TWO REACTIONS**

DME is formed in two stages: first, methanol is produced from synthesis gas, and then one molecule of water is eliminated with an acidic catalyst between two alcohols. Two-stage processes are somewhat inconvenient, especially if the intention is to use them for the continuous conversion of large quantities. “What’s more, the two reactions proceed at different pressures. And different catalysts are required,” says Schmidt, describing the problem. The search is on for a single catalyst that can carry out both reactions.

The chemists are thus producing small test quantities of nanostructured catalyst mixtures based on copper, zinc oxide and a solid acid component, and analyzing them using the latest methods. Then they test them head to head in a computer-controlled test plant in the historic development facilities. Fraunhofer engineers are in charge of process engineering aspects and are building a pilot plant in Oberhausen. The feedstock is wood chips, a starting material that is still very much uncharted territory for the industrial production of chemicals.

The DME project is a sign of things to come for the chemical industry, with process engineering also having to be rethought. “When you use renewable raw materials, you have to deal...”
with long-chain molecules. If they are to be functionalized as platform chemicals, it will have to be possible to carry out chemical reactions selectively in liquid multiphase systems,” explains Kai Sundmacher from the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg. In the InPROMT collaborative research center, his team is jointly developing novel process technologies with colleagues from TU Berlin, TU Dortmund, and the University of Magdeburg. Olefins obtained from biomass are mainly oily liquids. Homogeneous catalysis is the only way to bring them into effective contact with the catalyst, which means that the catalyst must be soluble. Unlike in heterogeneous catalysis, in which, for instance, synthesis gas reacts to a solid catalyst, a homogeneous catalyst requires troublesome separation after the reaction.

One solution to this problem could be switchable solvent systems. At present, the researchers are pursuing two paths in parallel: one approach provides solubilizing surfactants, which are added to an oil-water mixture or “multiphase system.” (The homogeneous catalyst is in the water.) “Within a specific temperature window, reverse microemulsions, consisting of nanometer-sized water droplets, spontaneously form in the olefin, and are stabilized by the surfactant. Because the interface between the phases is now enormous, the rate of reaction increases by several orders of magnitude.” After a temperature change, the liquids separate out again and the catalyst is largely left behind in the water. They are thus searching for the ideal surfactant and optimum temperature-switching conditions for the desired chemical reaction.

The other approach uses thermomorphic liquids. These are mixtures of two or three solvents of differing polarity that mix together completely or divide into two parts, depending on the temperature. The challenge is to identify the ideal solvent and the perfect mixing ratio for a particular desired reaction. Researchers are simulating all these factors using computer simulations and experiments in mini-plants, or production plants on a laboratory scale.

A POWDER CONVERTS METHANE TO METHANOL

Biomass might be able to replace petroleum and natural gas both as a raw material and as an energy source, but this will still take quite some time. Thus, in the meantime, it is vital to make the best possible use of fossil resources. We can’t go on wasting the methane that is released from wells in petroleum production. It can be used to make synthesis gas, from which, in turn, gasoline can be obtained. “That is why giant Fischer-Tropsch plants are currently being planned or built, or are already in operation, for example in Qatar,” explains Ferdi Schüth. However, the expenditure involved can’t be justified in many places, for example when methane escapes only in small quantities, known as stranded natural gas. “It’s usually simply flared off, resulting in the destruction of considerable quantities of energy sources.” But simply discharging it into the environment would be worse still, because methane is 25 times more climate-damaging than carbon dioxide.

However, this methane could be converted into something useful: methanol. “The solution could be small plants, for instance on ships, that are brought out to an oil platform to liquefy the gas on site for as long as extraction from the field continues,” says Schüth. It is, in principle, possible to oxidize methane directly to yield methanol. There is a catalyst that does this efficiently, but under truly caustic conditions. The soluble Periana catalyst, an organometallic, nitrogenous platinum complex that was developed in California in 1998, works only as a homogeneous catalyst, and then only in fuming sulfuric acid. “And as a result, it’s virtually unrecyclable.”

But sometimes the solution comes about by chance. While Schüth was thinking about the problem, his Max Planck colleague Markus Antonietti from Potsdam-Golm mentioned a chemical structure in a paper, giving Schüth pause for thought. “Adding platinum to this would result in a solid form of the Periana catalyst” was the thought that flashed through his head. Ferdi Schüth laughs. “Ninety-eight percent of such ideas are nonsense.” But in this case, it worked straightforwardly. When combined with platinum salts, the nitrogenous, graphite-like solid gives rise to a powder that can be used like the Periana catalyst.
“And now it can simply be filtered out.” Since then, the team has found similar, even more efficient materials. One problem facing methane liquefaction has thus been solved, at least in the lab.

And speaking of using waste materials, isn’t plastic waste a good raw material? Schüth plays this option down. “It certainly is possible, but one must ask if it makes sense to invest a lot of energy in it. A plastic bag has the same caloric value as heating oil. The thermal benefit wouldn’t be the worst.”

No stone is being left unturned. What impact will all this have on our energy supplies in a hundred years? “We will be harvesting solar energy efficiently,” says Ferdi Schüth, “and nuclear fusion is a major hope for the future.” That would have left us with more energy than we needed, thus solving several of the challenges facing a world with a population of ten billion in a single stroke. “When it comes down to it, almost everything is an energy problem: feeding the world is a distribution problem. Energy enables seawater to be turned into drinking water, and shortages of raw materials such as lithium and platinum can be overcome by reaccumulating these materials. After all, nothing on Earth is ever truly lost.”

Ferdi Schüth has to laugh and says: “But my predictions are just a linear extrapolation. Suppose it were 1850 and I had to make a prediction for today’s world. I would have failed miserably! I probably would have bet on faster horses and low-friction carriages.”

TO THE POINT

- Raw fossil materials are finite and damage the climate; biomass could replace them as a renewable source of energy and basic chemicals.
- Chemists from the Max-Planck-Institut für Kohlenforschung have found catalysts that break down cellulose and lignin, the essential components of biomass, into small molecules for fuels and chemical feedstocks.
- Processes developed at the Max Planck Institute for Dynamics of Complex Technical Systems are enabling the chemical industry to process oily, long-chain substances using water-soluble catalysts.

GLOSSARY

Aromatics: These compounds are named after the pleasant odor of the first members of the class to be identified. They contain a number of double bonds. These are arranged in such a way that electrons participating in the double bond are delocalized between several atoms in the molecule. This makes aromatics particularly stable.

Functional group: A characteristic structural unit of an organic molecule that determines its behavior, for instance in a reaction. When a molecule is functionalized, atoms of elements other than carbon or hydrogen, so for instance oxygen or nitrogen, are often introduced into a molecule, giving rise to, for example, acids, aldehydes or alcohols/amines.

Heterogeneous catalysis: The reactant and catalyst are present in different phases. In practice, the gaseous or liquid starting materials are usually passed over a solid catalyst in a reactor, and can then be collected at the other end. Some solid catalysts have to be added to the reaction mixture as a powder, and must therefore be filtered out after the reaction.

Homogeneous catalysis: The reactant and catalyst are present in a single phase, for example dissolved in a liquid. If it is to be possible to reuse the catalyst, which accelerates the reaction but is not consumed in the process, then the reaction mixture, which may also still contain the starting materials, must be subjected to a complex separation process.

Polymerization: The formation of long, sometimes branched chain molecules from many building blocks, usually of a single, but sometimes several, starting materials.

Hydrogen bridge bond: The electrostatic interaction between positively polarized hydrogen atoms, such as in alcohols or water, with negatively polarized atoms such as oxygen gives rise to a bond that is, however, weak compared with a bond created by a shared electron pair.
Carbon Acts as a Chemical Dating Agency

From plastic bags to hydrogen gas: almost nothing happens in chemistry without catalysts. The reaction accelerators often contain metals that are sometimes rare or need large amounts of energy to do their job. A research team headed by Robert Schrögl, Director at the Fritz Haber Institute of the Max Planck Society in Berlin, wanted to find out whether it was possible to do without catalysts.

Imagine you are standing at the top of the television tower in Berlin. Thousands of people are milling about in the city below, doing their shopping, visiting the Reichstag, going about their business. But it’s very foggy – you know all this only from messengers who drop in every now and then. And something else is strange: your sources tell you that people who come to the city as singles sometimes leave as married couples. Others come as a couple and are divorced when they board the Intercity Express to return home. You conclude that, among the thousands who are milling about below, there must be a few very industrious marriage registrars. Your job is to find out precisely who they are.

Crazy idea? Not quite. After all, this challenge is not dissimilar to the one that Robert Schrögl, Director at the Fritz Haber Institute of the Max Planck Society in Berlin, and his team faced a few years back. Strictly speaking, Schrögl’s job was even slightly more difficult. And not at all crazy. In fact, it was of quite crucial importance for the chemical industry. “The issue was the synthesis of styrene,” explains Professor Schrögl in a sunny office in the institute’s high-rise laboratory. “Styrene is an extremely important building block of such plastics as polystyrene and ABS, to name but two. So industry requires around 20 million tons of this monomer every year, which is an enormous amount.”

Chemical engineers around the world go to great lengths to be able to pump these 20 million tons of styrene into their reactors. The most important route to this polymer building block runs via a substance called ethyl benzene, from which the engineers remove two hydrogen atoms using a sophisticated process.

Things are not quite so simple in practice, of course, because the ethyl benzene is not prepared to let go of its hydrogen atoms so easily. This is where a so-called catalyst is needed – a compound that loosens firm chemical bonds, beckons oxygen and, at the end of a complex process, marries H and O atoms to each other without changing itself. In other words, a kind
A catalyst without any metal whatsoever: Carbon nanotubes remove hydrogen atoms from ethyl benzene, as well as from butane and propane, so that important compounds for the production of chemicals are created. They work much more efficiently than the metal oxides that have been used in industry to date.
discovered that it isn’t the sensitive metal oxide that converts the ethyl benzene into styrene, but a wafer-thin layer of carbon that deposits on the catalyst in the first minutes of the reaction like soot on the wall of a chimney.

METAL-FREE CATALYSTS WOULD OFTEN BE CHEAPER

This was a real surprise for the chemists: “It took many years before I believed it,” Schlögl confesses. “We even tried to refute this initially. It was one of the greatest revelations in my career – to realize that it isn’t the metal oxide, but actually the carbon that plays the crucial role in this process!” The revelation meant a completely new opportunity: If carbon does the work, is there any need at all to retain the sensitive metal catalyst below it? Would carbon not do the job on its own? And is it possible to completely forego metals in other catalysts?

Catalysts that don’t require metals would be beneficial in many instances. In the case of styrene production, many metalliferous catalysts require great amounts of energy to do their work, and others, like the catalysts used in electrolytic hydrogen production, consist of expensive precious metals. Metal-free catalysts would be helpful in using energy more efficiently and developing new energy sources.

However, the first attempts to dehydrogenate ethyl benzene with the aid of carbon compounds failed – graphite and even diamond simply did not want to do the job. It was time to take a closer look. Schlögl and his colleagues used a large number of extremely sensitive instruments for this. Their first really good lead was provided by a so-called Raman spectrometer. This device detects even slight changes to the surface structure in the scattered light of a laser beam. “The Raman spectrum showed peaks that shouldn’t have been there if the carbon was arranged as level as it is on the surface of graphite,” explains Schlögl. Instead, the bonds that the atoms formed with each other appeared slightly raised from the plane – the deviation was a mere one degree on average. Nevertheless, it was sufficient to radically alter the character of the surface.

But why was the carbon curved in this way? Probably because, in the styrene hell on a catalyst at a temperature of several hundred degrees, there is simply no time to weave the carbon atoms from the ethyl benzene into the regular hexagonal carpet that chemists call graphene, and that if stacked one on top of the other, produce graphite; every now and then, a ring closes too quickly and suddenly there is a bulge. Schlögl’s colleagues thus looked for carbon compounds that also had a
curved surface. The first attempt was again a failure – fullerenes, for example, didn’t work.

The scientists got lucky with the so-called multi-wall nanotubes, which consist of large numbers of nanotubes stuck one inside the other, a little reminiscent of rolled-up rabbit netting when viewed under a very powerful microscope. The surface of fullerenes has too great a curvature. The curvature of the top carbon layers in the thick multi-wall nanotubes, on the other hand, was just right. This type of nanotube, which is normally used to make plastics conductive, and which industry supplies by the ton, worked! And even better than conventional catalysts, at that. Without hot steam. And, most importantly, “With no metals whatsoever,” says Schlögl.

**ABSOLUTE CHAOS AS THE REACTION PROCEEDS**

But one mystery remained to be solved: How does a slightly rippled carbon surface do things that, until then, were assumed to be the prerogative of complex metal oxides? The decisive clue that put the researchers on the right track this time was the fact that the carbon catalyst always takes a while until the reaction really gets going; and it becomes all the more active the more oxygen it soaks up from the gas flow at the start. These two facts could mean only one thing: “The catalyst is only produced in the course of the reaction!”

This is the point where Schlögl and his crew suddenly found themselves in the television tower in Berlin, 300 m-
The mysterious atomic groups that got the catalyst going turned out to be diketones.

When chemists have to investigate such a muddle, their motto is: quantity counts. Since molecules are so incredibly minuscule, analysts need huge quantities of them to find out more. In addition, the complete reaction in the styrene reactor happens on the wafer-thin surface of a solid body. Its atoms account for only a tiny fraction of the catalytic grains that could be put under a measuring device. Although a liter of water with a drop of oil is, first and foremost, water, it is the oil film that gives it its taste.

The fact that Schlögl’s team ultimately succeeded in discovering the catalytically active carbon compound in this jumble is really a feat of detective work. “We simply tried to exclude all the possibilities one by one. What finally remained had to be the ‘guilty party’,” explains the chemist. In other words, he and his colleagues used methods precisely adapted to each particular case to remove carboxylic acids, phenol, lactone and anything else that could be found in the chaos on the catalyst’s surface. Overall, they made a foray through classic organic wet chemistry – under more stringent conditions, as the researchers had to work under extremely clean conditions to avoid introducing new impurities into their substrate with their reagents. And to ensure that they removed only the desired class of compounds without affecting others. All in all, it was around eight years of work.

The result, however, was another surprise for everyone: the mysterious atomic groups that got the catalyst going turned out to be diketones – compounds in which two adjacent carbon atoms are each connected to an oxygen atom via a double bond. Although these groups of atoms, also known as quinones, are well known in organic chemistry, the fact “that they are produced under these reaction conditions can’t be found in any textbook,” says a still-marveling Schlögl. Moreover, two adjacent oxygen atoms are permanently on call, so to speak, at a carbon seam at a temperature of more than 400 degrees Celsius. There is a risk that they will simply convert into carbon dioxide. But only a very small number of active centers are needed for a good catalyst to get a reaction going; if these are then also constantly reformed from the flow of material, even chemical mayflies will lead to success.

The key is that quinones have a very special trick up their sleeves. Under certain conditions, the two oxygen atoms
can exchange their electrons with each other like water in two communicating tubes – what chemists refer to as a quinone-hydroquinone redox pair. This makes the electrons sufficiently mobile to catch the hydrogen atoms of the ethyl benzene while still being able to back away again if the hydrogen atoms are to be surrendered to a passing oxygen molecule: an ability that, until now, had been credited more to metal atoms and their oxygen compounds.

Suddenly, everything fit together: for example, the strange observation that the speed of the styrene formation was dominated by the speed with which the catalyst combusts the stolen hydrogen atoms with oxygen to form water. “Until then, everyone believed it was the hydrogen abstraction that is crucial – which is also what the textbooks say,” recalls Schlögl. But this fits with quinones: they are very good at holding on to water molecules. The speed of the reaction thus depends on how fast a water molecule can free itself from the oxygen pincers of the quinone and make room for two new hydrogen atoms of the ethyl benzene.

SYNTHETIC QUINONE PROVIDES THE FINAL PROOF

The final proof for the catalyst ideas of the researchers in Berlin was then provided by a substance they had recently developed in collaboration with Klaus Müllen’s research group from the Max Planck Institute for Polymer Research in Mainz: practically a miniature section of the curved carbon surface including quinone groupings – and “tremendously active.”

Yet there was still a long way to go from this discovery into the reactors of interested styrene producers. It was important to immobilize the dusty nanotubes, for example, so that they can be easily poured into the reactor as a granulate and not endanger the staff working there – another job that took several years to complete.

But the goal seemed worth it because, as it turned out, the metal-free carbon catalyst was not only exciting from the point of view of a scientist engaged in basic research, but it was also the better alternative to the familiar metal catalysts in several respects. Not only because it works at around 400 instead of 600 degrees Celsius, but because industry can actually save the energy the conventional method needs to heat the vast amounts of steam. “The new method is simply more sustainable,” says Schlögl.

In addition, it reduces the problems resulting from the fact that the catalysts used thus far not only catch ethyl benzene, but also styrene, which they combine with steam to produce further compounds that the engineers must then laboriously filter out. This is where Schlögl’s versions are much tamer: “The carbon surface is hydrophobic,” says Professor Schlögl. “So it isn’t an attractive location for the steam to bond.” This means that Schlögl’s carbon catalysts can also convert other
hydrocarbons into valuable products, where metal oxides often miss the mark: propane into the polypropylene component propene and butane into butadiene – a component used by the chemical industry to produce millions of tons of rubber for tires every year, for example.

THE FIRST FACTORY TO USE NANO TUBES IS IN CHINA

First, however, catalysts similar to those developed in Berlin are being used as planned for styrene production – in China. There, oxygen and ethyl benzene are already rushing over around 100 kilograms of catalytically active nanotubes in a pilot plant – and helping engineers in the Far East improve their carbon footprint.

In the meantime, the search for metal-free catalysts continues, not only in Berlin. Robert Schlögl and his colleagues discovered that graphite produces a carboxylic acid from an aldehyde. Metal catalysts can sometimes be replaced with compounds of carbon and other elements, such as nitrogen. Nitrogen atoms in the carbon network of the nanotubes make them even more active as catalysts. Chinese researchers are testing such carbon tubes interspersed with nitrogen as electrode material in electrolytic cells that decompose hydrogen into hydrogen and oxygen. To date, precious metal electrodes have been required for this task.

Researchers working with Markus Antonietti, Director at the Max Planck Institute for Colloids and Interfaces in Potsdam, have, in the meantime, presented a catalyst that produces hydrogen directly from water with the aid of light. The photocatalytic material, which has a structure similar to graphite, consists of a network whose nodes are occupied by nitrogen and carbon atoms in turn. This carbon nitride could make one stage of the conventional electrolytic hydrogen production superfluous – when the light energy is first photovoltaically converted into electricity.

Carbon and mixtures of carbon and nitrogen are thus able to replace metal-iferous catalysts. Making the materials fit for this purpose is a real task of basic research, and one to which the Max Planck chemists will continue to devote their work. They are assisted in this task by what they have learned in their search for the precise location where ethyl benzene loses its two hydrogen atoms, “because now we really know the details of the chemistry of carbon surfaces well,” says Schlögl.

TO THE POINT

- Most industrially relevant catalysts contain metals that are often rare or need large amounts of energy to do their job.
- During the dehydrogenation of ethyl benzene to styrene, the actual reaction takes place, not on the metal oxides used as catalysts in industry, but on quinones, which form in a carbon layer above the oxide.
- Synthetic quinones produce styrene with higher yields and lower energy consumption than metal oxides.
- Metal-free catalysts from carbon or combinations of carbon and nitrogen are also suitable for hydrogen production by electrolysis or photochemical water decomposition.

GLOSSARY

ABS: A polymer produced from acrylonitrile, butadiene and styrene and used in automobiles, for example.

Dehydrogenation: Hydrogen is removed from a molecule.

Electrolysis: Electrical energy forces a chemical reaction. The reaction takes place in two partial reactions at two electrodes. In one of the partial reactions, a reactant accepts electrons, and in the other, a partner releases electrons, although this is energetically unfavorable. An example is the electrolysis of water to form hydrogen and oxygen.

Fullerenes: Spherical molecules of pure carbon. The best known example is the Buckminster fullerene, which consists of 60 carbon atoms and, like a conventional soccer ball, is composed of 12 pentagons and 20 hexagons.
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Mine, Mine, Mine!

A lack of impulse control prevents children from sharing fairly – even though they understand the benefits of sharing.

If children do not share fairly with each other, it may not necessarily be due to a lack of insight. They understand very early on that fairness and generosity can be beneficial. However, according to researchers at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, it takes some time before they possess the neuronal requirements to act in accordance with this understanding. Researchers tested children between the ages of 6 and 13 in various game situations in which the children were expected to share with another child. Most of the older children, like adults, made fairer offers if there was a chance that their counterpart could refuse the offer. If this happened, in this particular game, both parties left empty-handed. The younger children, on the other hand, did not behave more fairly in this game, running the risk that their partner would not accept an unfair offer and they would both end up with nothing. Measurements taken with a magnetic resonance scanner showed that the lateral prefrontal cortex – an area of the brain that, among other things, is necessary for controlling a person’s own behavior – was less active in younger children than in older subjects. (Neuron, March 8, 2012)

Sharing fairly at elementary school age – easier said than done: A region of the brain that holds the key to behavior control develops gradually in children.

Catalyst for Cleaner Air

The atmosphere has a robust capacity to clean itself, thanks to the consistent recycling of its cleaning agents – hydroxyl radicals. These are generated in the atmosphere by UV light, from water and ozone, and break down organic compounds in the air. Scientists at the Max Planck Institute for Chemistry in Mainz have now clarified exactly how the radicals are recycled. According to their findings, the reactive molecules can be produced when isoprene is broken down. As a key component of essential oils, isoprene is emitted into the atmosphere by plants, and is thus produced mainly in tropical rainforests. Until now, it was known only for consuming hydroxyl radicals during its chemical cleaning. This is also the case when there are high concentrations of hydroxyls in the air. At low concentrations, however, isoprene is broken down through a chemical mechanism in which more of the atmospheric cleaning agents are produced than are removed. Isoprene thus acts as a buffer that can diminish the increase in greenhouse gases and other air pollutants. (Nature Geoscience online, February 26, 2012)

The world maps show how efficiently hydroxyl radicals are recycled during the day and at night. During the day, they are formed mainly over forests, while at night, efficiency is generally high over continental regions.
Direct Genetic Exchange

Plants transfer the genetic material in their chloroplasts to contact zones

Grafting is a popular agricultural method for combining plant characteristics. But it is not only humans who enhance fruit trees and garden plants in this way – plants themselves also grow together naturally if they touch. Scientists at the Max Planck Institute of Molecular Plant Physiology in Potsdam discovered that the plants can exchange their chloroplasts together with their genes for photosynthesis. The genetic material in the transferred chloroplasts can even be passed on to the next generation. In their experiments, the researchers grafted two species of wild tobacco onto a cultivated species. Their analyses showed that the cultivated species transferred its chloroplast genome unchanged to the two wild species. Like bacteria, plants can also exchange genes without reproducing. Researchers do not yet know how the chloroplasts leave their original habitat and seek out a new cell. (PNAS, January 30, 2012, published online)

Powerhouse in the Crab Nebula

Pulsars are some of the most exotic objects in outer space. They are the remnants of burnt-out stars – extremely dense spheres of neutrons with a mass similar to that of the Sun, but with a diameter of just 20 kilometers. These neutron stars rotate on their axes for a period of between one millisecond and ten seconds, emitting charged particles. They move along magnetic field lines and emit radiation in almost the entire electromagnetic spectrum. If one of these beams crosses the line of sight, the star flashes for a moment, just like a signal from a lighthouse. The pulsar in the center of the Crab Nebula is particularly strong. This was confirmed by an international team of researchers that included scientists from the Max Planck Institute of Physics, using two MAGIC telescopes in La Palma in the Canary Islands. They observed the cosmic bundle of energy in the gamma-ray region from 25 to 400 gigaelectronvolts (GeV), a region that was previously difficult to access, and discovered that the pulsar emits pulses lasting approximately one millisecond with a maximum measurable energy of up to 400 GeV – at least 50 times more than theorists thought possible. “In the final analysis, there must be processes behind this that are as yet unknown,” says Razmik Mirzoyan from the Max Planck Institute of Physics. (Astronomy & Astrophysics, March 30, 2012)

Wandering Thoughts

While reading this article, it is highly likely that your thoughts will wander briefly, again and again. Despite this, you will still recall most of what you have read immediately afterwards. According to researchers at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, short-term memory allows humans to perform routine tasks while allowing their minds to wander. As the researchers determined in memory tests, there is a correlation between the mental working memory capacity and an unhindered stream of thoughts: participants in the study who had a greater short-term memory capacity allowed their minds to wander more frequently during routine tasks, yet still managed to perform the tasks without any problems. However, we are not completely at the mercy of the capacity of our short-term memory: by paying more attention to a task, we can compensate for a lower working memory capacity. (Psychological Science, March 14, 2012, published online)
Fossil Planets
Astronomers discover a solar system from the universe’s early days

The discovery of planets that orbit distant suns is part and parcel of everyday astronomical life. So the discovery of the new system around HIP 11952, a star with two planets located some 375 light-years away, is itself nothing special. However, HIP 11952 is 12.8 billion years old – in other words, it came into existence just one billion years after the Big Bang. “The planets probably formed when our galaxy itself was still a baby,” says Johny Setiawan from the Max Planck Institute for Astronomy. Consequently, the star contains essentially only hydrogen and helium, which were by far the most abundant elements in the early universe. All heavy elements – which astronomers call “metals” – were produced only over the course of billions of years inside stars, and then flung into space as supernova explosions. This, in turn, should favor the formation of planets, since, according to traditional models, planets emerge in metal-rich clouds around stars. This means that the formation of planets around metal-poor stars should be an extremely rare occurrence. However, astronomers discovered another solar system of a similar age just two years ago. They conclude from this that new planets are obviously formed during all periods of cosmic history. Why and how? The researchers want to conduct further observations to find out. (ASTRONOMY & ASTROPHYSICS, March 5, 2012)

Molecules as Radio Stations
Radio communication is now possible at an elemental level: Scientists at the ETH Zurich and the Max Planck Institute for the Science of Light in Erlangen used two molecules as antennas and transmitted signals between them in the form of individual photons, or light particles. Since a single photon usually interacts very little with a molecule, the scientists had to use some experimental tricks to ensure that the recipient molecule registered the light signal. This included, for example, directing the transmitted photon to the recipient molecule using powerful lenses. They also matched the color of the emitted photon very closely with the color that the other molecule can receive. A radio connection communicated through individual photons would be suitable for various applications of quantum communication, such as quantum encryption, or in a quantum computer. (PHYSICAL REVIEW LETTERS, February 27, 2012)
Followers Foster Democracy

The majority attracts undecided individuals to its side

Social beings must reach decisions jointly, regardless of whether they live in a shoal of fish or in human society. In some cases, a small, resolute group may succeed in bending the whole community to its will. The commonly held view is that such groups will always be successful when they are faced with many poorly informed and undecided individuals. Using computer models and behavioral studies of fish, a group of researchers that included colleagues from the Max Planck Institute for the Physics of Complex Systems discovered that poorly informed individuals tend to support the majority rather than a particularly determined minority.

The researchers based their models on just a few generalized assumptions. The results thus apply to all systems in which individuals prefer to follow one another rather than engage in conflict. Applied to humans, this means that uninformed and therefore undecided individuals can facilitate a democratic outcome, as they prevent a minority from taking control. However, the calculations also show that the number of poorly informed individuals must not be excessive. In such cases, the decisions follow a random pattern. (Science, December 16, 2011)

From Specialist Straight to Multitalent

Scientists at the Max Planck Institute for Molecular Biomedicine in Münster extracted somatic stem cells from fully differentiated somatic cells in mice. Using a combination of growth factors in which the factor Brn4 plays a key role, the researchers transformed skin cells into neuronal stem cells. Prior to this, a detour through pluripotent stem cells was required. These cells are capable of developing into any type of cell in the body. However, they have such a degree of plasticity that they can also transform into cancer cells and form tumors. The somatic stem cells generated with Brn4 pose a lower risk of cancer, as they can form only certain types of tissue, in this case nerve tissue. The scientists now want to examine whether human cells behave in a similar way to mouse cells. (Cell Stem Cell, April 6, 2012)

Dyed neuronal stem cells: The cell membranes are highlighted with red dye, and the cell nuclei with green and blue.

Sweet against Sugar

It is used as a raw material in licorice, calms the stomach and helps alleviate respiratory diseases: licorice root. The Medicinal Plant of 2012 has been cherished in traditional healing since ancient times. Researchers at the Max Planck Institute for Molecular Genetics in Berlin have now discovered that licorice root also contains substances that have an anti-diabetic effect. The amorfrutins, as they are known, not only reduce blood sugar, they are also anti-inflammatory and are very well tolerated. The health benefits are based on the fact that the amorfrutin molecules dock directly onto a receptor in the cell nucleus called PPAR. This activates various genes that reduce the plasma concentration of certain fatty acids and glucose, which is a sugar. The amorfrutins could possibly be used as nutritional supplements or as mild remedies that are individually tailored to the patient. To find out for sure, the researchers will now have to test the effect of the substances on diabetes patients. (PNAS, April 16, 2012, published online)
Climate Archive in Glass Sponge

11,000-year-old deep-sea sponge provides a record of previous environmental changes in the sea

Climate researchers have discovered a new archive of historical sea temperatures. Using the skeleton of a glass sponge belonging to the *Monorhaphis chuni* species that lived in the East China Sea for 11,000 years, an international team of researchers headed by scientists from the Max Planck Institute for Chemistry were able to show that the deep-sea temperature changed several times in recent millennia. The skeleton, which is one centimeter thick and two meters long, resembles a glass fiber rod. The sponge, whose cells surrounded the glass rod during its lifetime, constantly formed new layers of silicon dioxide. Based on isotopic and elemental analyses, the researchers concluded that the sea temperature in the sponge’s environment increased at least once from just under two degrees Celsius to between six and ten degrees Celsius. These changes in temperature were not previously known about and can be traced back to seamount eruptions. (Chemical Geology, March 18, 2012)

Hungry Dwarf Galaxy

The little ones always grow up. This is no less true of the universe: tiny galaxies merge to become impressive galaxy systems. But how do dwarf galaxies grow? In a similar way, it seems: through cosmic cannibalism. Two groups from the Max Planck Institute for Astronomy discovered a mini-galaxy that is currently “eating” another one. They found that a small companion of the NGC 4449 dwarf galaxy in the Canes Venatici constellation is actually an even smaller galaxy system that is just about to be swallowed up by NGC 4449. The researchers also studied the shape of the distortion, analyzed the star types and searched for structures that trace the orbit of the galaxy that is about to be devoured. (Nature, February 9, 2012)

Cosmic meal: The NGC 4449 dwarf galaxy (top left) is in the process of devouring an even smaller galaxy (bottom right). The inset came from the 8.2-meter Subaru telescope and resolves the smaller galaxy into individual stars.
Microlenses – Formed Naturally

Materials scientists can sometimes learn from very simple organisms. Scientists at the Max Planck Institute of Colloids and Interfaces are manufacturing simple, inexpensive and top-quality microlenses from calcium carbonate. Their work is inspired by the brittlestar *Ophiocoma wendtii*, a relative of the starfish, whose skin is studded with such lenses. Like the brittlestar, the Max Planck researchers are using just one organic substance – in this case a surfactant – with which the tiny crystal lenses form on the surface of a calcium-saturated solution with the carbon dioxide in the air. Such microlenses are of technological interest in the processing of optical signals, for instance in telecommunications. Until now, it has been possible to manufacture these types of lenses only in very complex processes, for example using semiconductor technology. (Nature Communications, March 6, 2012)

Nasal Spray for Panic Attacks

Anxiety-reducing substance can reach the brain through the nose

Tablets that are intended to have an effect in the brain must overcome the blood-brain barrier. This can mean that a lot of the original active substance is lost. Using mice, Max Planck researchers have now demonstrated that the anti-anxiety substance neuropeptide S can also be absorbed through the nasal mucosa and deliver its effect in the brain. Scientists from the Max Planck Institute of Psychiatry in Munich succeeded in visualizing the path taken by the intra-nasally administered substance to special neurons in different regions of the brain. Neuropeptide S reached the brain just 30 minutes after administration through the nasal mucosa. The anxiolytic effect of the substance was achieved after four hours. Neuropeptide S clearly influences the transmission of signals between neurons in the hippocampus, an important brain structure for learning and memory. The substance will have to undergo a battery of tests before it can be used on humans. (Neuropsychopharmacology, January 25, 2012, published online)

Help in a little bottle: An anti-anxiety spray is still a long way off, but Max Planck scientists are working on it.
Single atoms can’t be grasped through everyday experience: even a drop of water or a microorganism is made up of countless numbers of them. But Gerhard Rempe, Director at the Max Planck Institute for Quantum Optics in Garching, uses single atoms to study the interaction between light and matter at the most elementary level. The work that he and his team perform is creating the foundations for a future quantum internet.

TEXT ROLAND WENGENMAYR

The sun draws us outside on this fine afternoon. We are sitting in front of the cafeteria at the Max Planck Institute for Quantum Optics in Garching, near Munich. Gerhard Rempe clearly enjoys the campus atmosphere. Especially the warm sunlight feels good, and that brings us straight to the core of the physicist’s field of research. In order for us to be able to see the scenery around us, our eyes must receive light. The sun’s rays excite countless atoms to emit light, and atoms in the retinas of our eyes capture a portion of that light.

“The interaction between light and matter is utterly essential for our research,” says Gerhard Rempe, kicking off the intellectual game that will gradually take us to the limits of current physics knowledge. It will cover the quantum world and its apparent peculiarities. We will discuss Schrödinger’s cat, entangled quantum states and the question of how large such quantum objects can become. In other words, we will be concerned with how it might be possible to use quantum physics to build future quantum networks and quantum computers.

In Rempe’s division, young physicists are busy carrying out various experiments. However, one extreme experiment runs through Rempe’s research as a common – or, more appropriately – luminous thread. It involves two nearly perfect mirrors between which a single atom floats. “These are the best mirrors in the world,” the Max Planck Director comments. The Garching-based scientists animate the atom in its mirror cabinet to either emit or absorb a single light quantum (photon). In other words, they reduce the process that occurs billions of times in the midday flood of light to its fundamental constituent. In experimental physics, radical reduction is a key to new discoveries. But why an atom and a photon?
Gerhard Rempe illustrates the principle of the optical resonator: Between two mirrors, light is reflected back and forth, increasing the interaction of a photon with a single atom.

A single mirror in its mount. The inwardly curving surface with a diameter of about 1.5 millimeters reflects nearly perfectly the infrared light with which the atoms are excited.

Before the researchers install the mirror in the optical resonator, they use a special microscope to examine the surface for flaws.
This seemingly simple arrangement makes it possible to study “very, very” fascinating properties of quantum systems in their purest form, emphasizes Gerhard Rempe: “Such small systems allow one to penetrate into areas of quantum physics that are not accessible to large systems.” Experiments with many atoms always reveal only average properties of large ensembles – just as one can’t hear a single violin in an orchestra.

But such a pure “sound” is what, figuratively speaking, physicists want to explore when they use a single atom to examine elementary quantum systems. In this way, they learn how the quantum building blocks of nature work. Their findings will thus paved the way to a future quantum information technology.

A CABINET WITH TWO SUPERMIRRORS

Furthermore, with sophisticated experiments, they can take the game between single atoms and photons to its extreme. “And we do want to play,” says Rempe. “That’s the only way basic research will work.” The scientists in Garching have, indeed, made some exciting observations in this fundamental field that made Max Planck and Albert Einstein the discoverers of the quantum world more than a hundred years ago.

But how does one get a single atom to float between two mirrors? Christian Nölleke, a doctoral student who works in Rempe’s department, explains this in the lab: “First, we produce a cloud of up to a million rubidium atoms.” The physicists capture these atoms with a magnetic-to-optical trap – that is, with laser light and magnetic fields – and largely freeze their motion. Since motion is synonymous with temperature, this cools the cloud to just above absolute zero, or minus 273.15 degrees Celsius. From this ultracold cloud, the physicists then use light tweezers to kick atoms between the mirrors. As soon as one reaches the resonator center, the electronics captures it with light. “This takes just a few seconds,” explains Nölleke. And why are the mirrors so important? This question is of fundamental significance for Gerhard Rempe. “Such an atom is very small,” he explains, “and when I shine light on it from somewhere, my photons miss it entirely.” This problem can be solved only by using the trick with the cabinet made of two mirrors. “When we look in the bathroom mirror, we have a pair of ourselves,” says Rempe, “and if we then hold a second mirror behind us, many mirror images are created.” The perfect mirrors in Garching could produce an incredible hundreds of thousands of mirror images, but no head would fit between them. They are spaced approximately a hundred micrometers (millionths of a meter) apart.

A photon is now tossed back and forth between these mirrors hundreds of thousands of times like a ping-pong ball. It will inevitably hit the atom eventually. Even if, conversely, the atom emits a photon, the resonator ensures a welcome behavior. “For the luminous atom, due to its mirror images, it looks like hundreds of thousands of other luminous atoms there, all radiating light waves in exactly the same rhythm,” says Rempe. This chain of virtual blinking quantum lights animates the atom to emit its photon precisely along this chain. This allows the Garching-based physicists to systematically find the extremely weak glow of the atom and work with it.

“This light is ideal, as it always consists of a single photon,” says Rempe enthusiastically. “There are never zero or two photons.” Many experimenters have racked their brains for years about how to obtain such single photon sources. Even extremely weak, pulsed lasers normally emit a randomly fluctuating number of light quanta per light pulse. Currently, only one atom between the mirrors can fire off exactly one photon at the push of a button, as it were. And only these light sources permit fundamental quantum operations like those required for a future quantum information technology.

“We’re known here as cavies,” says Christian Sames, by way of introduction, as we stand in the lab in front of such a resonator experiment. The nickname is a play on the word “cavity”.

The doctoral student explains that the atom, together with the highly cultivated mirrors, forms a kind of molecule. What happens then can be understood if we recall that electrons in the atoms can absorb or emit light only in quantum jumps.

LIKE THE STRINGS OF A MUSICAL INSTRUMENT

These tiny quantum jumps occur between the steps of an energy ladder. The ladder forms because quantum particles such as electrons also exhibit wave properties. And the wave trains of the electrons must fit exactly around the atom: when closing this loop, a wave peak must merge into a valley without a jump.

In other words, the quantum states behave like the taut strings of a music instrument. In a molecule, the atom is now approached very closely by other atoms, which put the strings out of tune. In Garching, this is the function of the mirrors, instead, acting like the sound box of an instrument. In this way, they simulate a sort of molecule that consists, in part, of the atom, and in part of the light field between the mirrors.

With their single atoms in the resonator, the researchers can now tap the properties of their novel molecule – half atom, half light – for novel applications. They can use it to systematically excite it, for instance with a laser beam, into the second quantum state, such that it then emits exactly two photons. In principle, this also works with three and more photons. “This gives us, for the first time, the possibility to use an atom to emit two photons, which normally doesn’t happen in nature,” says Rempe.

Such sophisticated possibilities could spawn completely new components of a future quantum information technol-
1 Christian Nölleke adjusts the laser system. Seen in the foreground is the optical construction in which the researchers produce various laser beams having precisely defined properties. They use the light to control the motion and the quantum state of the atoms.

2 Christian Sames works on the apparatus that feeds laser beams into the optical resonator. This resonator is located in the steel vacuum chamber. In the foreground is part of the detection structure, which facilitates the detection of even very weak light fields.
ogy – but just which one is not yet known even to quantum physicists. Even if it should involve quantum communication, Gerhard Rempe’s team is an international frontrunner. “Our goal is to one day build a quantum internet that sends, for example, quantum states,” admits the scientist, “or facilitates a quantum connection between two quantum computers, once such a thing comes into existence.”

“We are particularly proud of the fact that we managed to get a very effective pair of laser light tweezers inside the narrow resonator,” says Sames. After all, even a well cooled atom still moves a little and threatens to disappear from the resonator center. Superfast control electronics detect this based on the weakening of the flow of single photons the atom emits. Then the light tweezers turn on briefly and push the drifting atom back again. Using this technique, the Max Planck physicists are now able to keep the atom trapped in the resonator for several minutes. “Our record is eight minutes – for our field, that is a short eternity,” says Gerhard Rempe excitedly. “It’s the time light takes to get from the sun to the earth.”

The researchers just achieved a further success that also demonstrates how the field is still very much in its infancy. Transferring quantum information on photons as flying quantum bits is almost routine today. What had not yet been solved, however, was the problem of storing the highly sensitive quantum information again, unharmed, in a resting quantum bit – and then later reading it out again, as is done on memory chips in conventional computers. Rempe’s team has now built the first such storage element. But why is that so difficult?

The challenge lies in the fact that it must be guaranteed that the extremely sensitive quantum information is transferred to the recipient unread. One can imagine this as something like a sealed letter that one must not even hold up to the light to decode words that show through the envelope. In the quantum world, even that would immediately destroy the entire message, leaving only the scraps of words that were glimpsed intact.

That is what distinguishes quantum bits – qubits for short – from conventional bits: the latter can be read and copied without loss. That is why one can, for example, easily transfer conventional bits from hard drives to light pulses that shoot through fiber-optic networks.

But in quantum physics, reading and writing is usually a measurement process, which changes the information-bearing system. The reason for this is that a quantum system always simultaneously harbors multiple possibilities for realizing a certain physical variable. Conducting a measurement realizes one of these possibilities, but in doing so, it destroys all other variants. That is exactly what happens in a conventional copying operation.

**MONEY IN BANKS CONSISTS OF BITS**

The quantum information must therefore be transferred under complete protection from curious observers. In quantum mechanics terms, an observer is essentially anything that influences the quantum system. Many kinds of perturbations from the environment are also the reason why the peculiar quantum effects don’t normally make it onto the macroscopic scale of our everyday world – the world of large things.

This sensitivity of quantum information gave physicists the idea that it could be used as a key for absolutely secure communication. Any attempt at espionage would inevitably reveal itself in the collapse of the information. Gerhard Rempe thus sees this quantum communication as an interesting field of application for his research: “Money in banks, for example, invariably consists only of bits, and they must be protected.”

Bank transfers have, in fact, already been quantum-cryptographically encrypted. One can even purchase commercial systems. To date, however, all of them have the problem that they can write the quantum information in photons once, as flying qubits – and at the end, read it out once. Then the information is destroyed. But in fiber-optic networks, photons don’t make it much farther than a hundred kilometers. Thereafter, at the latest, repeaters have to give the weakened pulses of light a fresh boost. That’s how it works in the global fiber-optic networks. But since such a boost is also a measurement, it destroys the quantum information.

The key lies in the possibility to restore the quantum information from a flying qubit in a stationary qubit. Such a memory could then be further developed into a quantum repeater. Rempe’s team has, as the first in the world to do so, now succeeded in building a true cache memory. For this, they connected a single rubidium atom in a resonator via a 30-meter-long fiber-optic cable with an ultracold cloud of rubidium atoms. These approximately one million floating atoms form a large, collective quantum object known as a Bose-Einstein condensate.

For the researchers in Garching, it served as cache memory. As quantum information, they used a quantum property of the electron in the single atom, namely the spin. This spin can be imagined as a small pointer. Using a laser
pulse, the team in Garching caused the atom to send a photon with this spin information through the fiber optics to the Bose-Einstein condensate.

There, a synchronized laser pulse stored this information in the cold atom cloud, thus distributing it across many atoms. Using a further laser pulse, the physicists perfectly released the stored photon from the atom cloud again. “The photon flew on beautifully in the same direction as before storage,” says Rempe, clearly pleased. “We were surprised at how well that worked.”

So, in the transfer of sensitive quantum information between the single atom in the resonator and the Bose-Einstein condensate, a role was played by a quantum effect that has become the very symbol of the apparent madness of the quantum world: this entanglement formed, along the chain of transfer comprising the single atom, the photon and, ultimately, the ultracold atom cloud, a collective, extended quantum object.

An entangled quantum object has peculiar properties. Its components – such as atoms and photons – can be very distant from one another. Nevertheless, all partners feel, with no time lag whatsoever, the moment certain quantum properties of even just one of them are manipulated. This seems to contradict the theory of relativity, which stipulates the speed of light as a strict limit for the propagation of physical interactions.

THE CAT IN THE BOX IS ALIVE OR DEAD – OR BOTH

Quantum physics salvages this situation, as it always considers all system components together and never separately. There is therefore fundamentally no sending of information faster than the speed of light by entanglement transmission. Still, all of this runs so contrary to our everyday notion of a local physical reality that Albert Einstein took entanglement as proof of the incompleteness of quantum mechanics.

Now it is clear: Quantum mechanics describes nature completely and correctly. Entangled quantum objects can be produced and used in technology. Moreover, quantum mechanics sets absolutely no theoretical limit for the extension of entangled objects, as long as they are shielded well enough from environmental perturbation. Of course basic researchers like Gerhard Rempe want to test whether or not it is, in fact, possible to produce arbitrarily large quantum objects.

The quantum-like connection between the single atom at one end of the fiber optics and the cold atom cloud at the other end is, in principle, also something that, in physics, is known as Schrödinger’s cat. In 1935, Austrian physicist Erwin Schrödinger came up with the thought experiment in which an unstable atom, upon its radioactive decay, triggers a mechanism that poisons a cat. All of these components are located in a box. As long as the box remains closed, no one knows whether the cat is still alive or has already died. It isn’t possible to predict when the atom will decay, because chance has absolute reign over the quantum world. Thus, in the jargon of quantum physics, one can only record: as long as the box is closed, the two states – “cat is alive” and “cat is dead” – are superimposed.

With this exercise, Erwin Schrödinger wanted to show what consequences a direct connection between the micro-world of quanta and our macro-world would have. What, at the time, was an intellectual game is now increasingly becoming a technological reality. “In any case, our Bose-Einstein condensate already has a million atoms,” stresses Rempe. Even if a cat is made up of considerably more atoms, perhaps that is only a slight difference.
However, the physicist points out that “The cat possesses awareness and should thus know whether it is still alive.” This self-observation would be a measurement process that, according to the laws of quantum theory, should actually destroy the experiment. What would happen in reality remains unresolved.

Gerhard Rempe obviously enjoys contemplating potential limits of quantum physics. Now, however, he steers the conversation back to technology. Today, the Garching-based researchers successfully replaced the Bose-Einstein condensate with a second resonator with a single atom. Here, too, the storing of the photon-transferred quantum state worked, giving the mini-quantum network in Garching – the only one of its kind in the world – not just one, but two similar storage nodes.

That is a key step toward realizing Rempe’s dream of one day building a quantum internet. What all it could be used for, besides securely transmitting messages and connecting quantum computers, is still open. But the inventors of the laser also had to endure quite a bit of ridicule in the beginning – and still they initiated a technological revolution.

Stepping out of the lab and back into the daylight, it seems like the hours have flown by. Gerhard Rempe offered some insight into the thought-world of physicists who deal with quantum systems day in and day out. The result is a change of perspective.

“...” says Rempe with a grin, “so that we really doubt conventional physics.” But before the rug is completely pulled out from under the certainty regarding our everyday world, a loudly chirping bird brings us back to reality.

TO THE POINT

- Single atoms in a resonator provide insight into the behavior of single quantum particles, while standard experiments with many atoms permit statements only about average properties.
- Information can be stored in an atom between two mirrors, and also be systematically read out again; moreover, the information can be transferred from an atom to a Bose-Einstein condensate and temporarily stored there.
- The experiments create the conditions for using single atoms in resonators for quantum information technology – for instance in a quantum internet.
- It is still unclear what the maximum size is for objects to behave like quantum objects and, for example, become entangled. In any case, a Bose-Einstein condensate composed of a million atoms can be entangled with an atom.

GLOSSARY

Bose-Einstein condensate: An ultracold, gaseous quantum object composed of thousands or millions of suitable atoms (bosons), in which said bosons, when cooled, condense to a few millionths of a degree above absolute zero.

Quantum bit: The smallest unit of quantum information – qubit for short. Conventional bits encode two states: 0 and 1. Qubits also have two such quantum states. In a suitable measurement, they jump to “0” or “1.” Before the measurement, however, they also have the quantum mechanical superimposition of both states. This additional quantum information is missing in conventional bits. In photons, a qubit is, for example, the superimposition of two oscillation states.

Quantum information/quantum communication: Uses the properties of quantum bits, especially entangled qubits.

Resonator: In optics, a “resonance chamber” made of two nearly perfect mirrors between which light quanta (photons) are reflected back and forth.

Entanglement: Entangled quantum systems form a quantum object. Any measurement of one of the partners instantly determines the measured property – so for photons, for example, the oscillation state – for the other partner as well. The photons can, theoretically, be millions of kilometers apart from each other.
How Light Gets on the Nerves

The ragworm is an unusual laboratory animal. However, for Gáspár Jékely of the Max Planck Institute for Developmental Biology in Tübingen, this marine inhabitant has all the qualities of a perfect model organism: the larvae possess the simplest eyes in the world and later develop a simple nervous system made up of just a few hundred cells. This means that the scientist can track how sensory stimuli trigger behavioral changes.

TEXT STEFANIE REINBERGER

In Tübingen, the sea is up a slope. To be more precise, it can be found in the basement of the Max Planck Institute for Developmental Biology, located on a hill in the north of the city. This basement houses a tank containing 1,000 liters of seawater. Every month, a tanker truck drives up to replenish supplies. The watery cargo is intended for Gáspár Jékely’s lab animals, namely ragworms, known by the scientific name Platynereis dumerilii.

“These animals are really low-maintenance,” says the biologist, who comes from Hungary. “All they really need to keep them going is plenty of fresh seawater.” Plus a lamp that imitates the phases of the moon, which synchronizes the breeding of the animals. They can be fed with fish food and spinach leaves. These worms, which are found throughout the world’s oceans, aren’t particularly demanding.

A SIMPLE NERVOUS SYSTEM IS ENOUGH FOR SURVIVAL

But this easy-care aspect isn’t the only reason Jékely chose these unusual study subjects. The head of the “Neurobiology of Marine Zooplankton” research group wants to understand how simple nervous systems work and how they have developed over the course of evolution. It’s no wonder he’s diving into the sea to do this: “Life comes from the sea, and the first neurological systems also evolved there,” says Jékely. In addition, the ragworm Platynereis dumerilii is regarded as a living fossil. For millions of years, it has existed virtually unchanged in the coastal waters of temperate and tropical oceans.

Intriguingly, the worm’s larvae possess, during their first days of life, the simplest eyes in the world. Each eye consists of a single photoreceptor and a single pigment cell, which screens...
Ventral view of a young ragworm (*Platynereis dumerilii*), about half a millimeter in length, under the scanning electron microscope. The mouth opening (top) is surrounded by spherical and thread-like appendages with which the animal can perceive chemical stimuli from the environment.
the sensory photoreceptor cell on one side. This exactly matches Darwin’s idea of the prototype eye: as early as 1859, the father of the theory of evolution speculated that the visual organs of all living creatures might have evolved from a simple system – a light-sensitive sensory cell and a pigment cell. “When we study the larva’s eye-spots, we come as close as we can possibly get to the evolutionary origin of the eye,” says Jékely.

Of course, with their simple eyes, the ragworm larvae can’t see in the true sense of the word. But they can tell light from dark, and will swim toward light sources. To prove this, the scientist opens the door of the lab’s refrigerator and takes out one of the little date-labeled glass beakers. It contains two-day-old larvae. But the naked eye can make out only water and some fine, floating particles, as the larvae are still just 0.2 millimeters in size.

The light microscope, however, reveals the outlines of some tiny, transparent bubbles that have a little dent on one side, marking the head region.

This gives them the shape of a miniature hazelnut. “Look what happens next,” says Gáspár Jékely. He holds the microscope lamp against the side of the beaker. And presto – the minuscule larvae move toward the light, head first.

This swimming toward the light, also referred to as phototaxis, is important for the annelid’s spread and survival. The larvae use the surface water currents to travel long distances until they find a suitable environment in which to settle and grow into mature, bottom-dwelling worms.

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1. To label individual cells in the ragworm’s body, Gáspár Jékely stains them with pigments coupled to special antibodies.
2. Mature specimen of *Platynereis dumerilii*. Each of its body segments, all of them similar, carries a pair of legs that the worm uses to move along with a crawling motion. The animal can regenerate any damaged or severed segments.
3. On its head, the ragworm carries two pairs of eyes (dark brown), as well as four pairs of thread-like processes with sensory cells. Pigment cells on the body give the animal its coloring.
When we study the larva’s eyespots, we come as close as we can possibly get to the evolutionary origin of the eye.

For a long time, it was a complete mystery to scientists how the larvae, with their simple two-cell eyes, could achieve this type of sensory skill and swim accurately toward the light. Until Gáspár Jékely, together with his colleagues at the European Molecular Biology Laboratory (EMBL) in Heidelberg, finally solved the puzzle: the photoreceptor is directly linked to the larva’s locomotion system. Below the head region, the larva sport a dense wreath of cilia, rather like a collar. The beat of these tiny hairs propels the animal forward. A nerve fiber connects the cilia with the eyespot.

When light hits the sensory cell, it sends a signal to the cilia on that side of the body, which then beat more slowly. This makes the driving power one-sided, and the larva go into something of a tailspin. They not only swim forward, but also rotate around their own axes. They not only swim forward, but also rotate around their own axes – until the light hits the photoreceptor on the other side of the body. The ciliary beat on that side then slows down, and the larva continue to rotate and are driven even further toward the light.

“From computer calculations, we know that only such spiraling locomotion can function in an organism with such basic equipment,” says Jékely. That is, as a result of the rotating movement, the light repeatedly hits the photoreceptor cell. The cell doesn’t adapt to the stimulus; instead, it is repeatedly re-stimulated, thus constantly controlling the beat of the cilia.

“We are, in fact, working with the simplest neuronal system in the animal kingdom here: a sensory cell that directly controls an organ of locomotion as a single neuron,” says the Max Planck researcher. “We suspect that this sort of direct link also existed in the first eyes that appeared early during evolution.”

A MODEL OF EVOLUTIONARY SUCCESS

Incidently, the ragworm offspring aren’t the only ones with this light-powered locomotion system: the larvae of mussels, sea cucumbers and flatworms also move in this propeller-like fashion. They also possess phototactic equipment of comparable simplicity; it would seem that the “direct-drive” eye has caught on.

But the scientists in Jékely’s group have only a short time window in which to study these proto-eyes. They therefore need a constant supply of new larvae from their ragworm farm in the building’s basement. The time for the eye prototype runs out in just three days. Interestingly, the larva’s first simple pair of eyes degenerates as it matures. In their place, new visual organs are formed a bit further back on the head. These replacements are now more advanced, and consist of an increased number of photosensor cells, a pigmented cup and even a simple lens. They are the precursors of the adult animals’ eyes. The fully grown ragworms possess two pairs of them, each pointing in a different direction to cover the maximum possible visual field.

It’s as if several stages of evolution can be seen in a single animal. It may be that the genome of the ancestors of today’s Platynereis representatives contained two copies of the genes that code for light perception. Evolution was thus at liberty to produce a new biological variant: a complex eye with which the animals could truly perceive their environment.

With its very simple eye, one pigment cup and one lens, Platynereis dumerilii makes an ideal study subject for researchers like Gáspár Jékely. Further-
more, as they develop, the larvae form more and more nerve cells – like a sort of primitive brain. These nerve cells include a great variety of different cell types, even ones that were long thought to exist only in vertebrates. Jékely points to a picture on his office wall. It shows a larva in cross section under the microscope. The animal is encircled by its ciliary band, with a network of various brightly colored nerve cells in the middle.

“This provides us with a model for a very simple nervous system that we can use to study the function and interaction of various cell types," says the scientist. Colleagues who work with mice or rats, or even try to unlock the secrets of the human brain, have a much harder time. “When faced with brains made up of many millions or even billions of neurons, it is incredibly difficult to stay on top of things," explains Jékely.

So, anyone searching for basic connections at the cellular level would be well advised to get hold of a simple, manageable system – as manageable as that of the ragworm larvae. They even allow us to observe directly how single nerve cells control behavior.

The Hungarian scientist and his team are working on a sort of map of the larva’s nervous system. In this map, the scientists aim to make a record of which nerve cells react to certain environmental signals, and what behavior results from this. Stimuli from the microscopic animals’ environment – such as light, water temperature or even chemicals – don’t just determine the direction in which they swim. Rather, environmental signals appear to steer their entire development. The larvae thus bob around in the water until they find themselves in an environment that is suitable for them to settle on the ocean floor. It is only then that their body segments are formed and that they mature into full-grown ragworms. “How the larvae recognize this is not yet clear," says Jékely. “It’s possible that it involves a chemical signal that originates from a food source."

MESSENGER SUBSTANCES CONVEY ENVIRONMENTAL STIMULI

The number of potential external stimuli is enormous. To start from this end and feel one’s way toward the nervous system’s reactions and the resultant behaviors of the animals would be like looking for the proverbial needle in a haystack – particularly when one considers the great multitude of chemical stimuli emanating from the environment. The Tübingen-based Max Planck researchers are approaching the problem from the opposite end, by first putting the function of the neurons themselves under the microscope.

In this way, the scientists identified a series of neuropeptides that the worm larva’s various nerve cells use as messenger substances. Among them, the researchers found representatives such as enkephalin and serotonin, which occur not only in the ragworm, but also in vertebrates. And, in 2011, they were able to prove that the animals also control their swimming depth with the aid of these signal molecules. After all, life is not all about swimming toward the light. During the dark nights, for instance, they would then simply sink to...
A pipette ensures particularly gentle handling of the ragworm. This allows the researchers to transport the fragile animals without risk of injury.

The worms build dwelling tubes (black) in their tank, and leave these tubes only when they are sexually mature. They are then collected by the researchers and paired off. The purple color is produced by the algae on which the worms feed.

Platynereis thrives in shallow dishes filled with seawater. This allows a large number of animals to be kept and bred at the ragworm breeding station.
the bottom of the sea, where not a single ray from the sun would reach them the next morning.

The larvae maintain a fairly constant swimming depth. The researchers observed this by letting the tiny animals swim in transparent columns and following their movements with a camera. Normally, the larvae’s ciliary beat ensures that they are propelled upward. If the cilia stop beating for a short time, the animals sink. Consequently, the larvae remain at the same water depth by keeping their upward and downward movement equal. The animals can tell whether they are too far from or too close to the surface through sensory stimuli such as light, temperature and pressure.

The neuropeptides act as messenger substances in this process. In a test, the scientists added several of these substances to the water. These signaling chemicals diffuse through tiny pores to reach the larvae’s interior, where they deliver their messages to the corresponding nerve cells or directly to the ciliary band. And, indeed, nine of the tested substances stimulated the ciliary band to increase the beat frequency of the delicate cilia hairs, making the larvae swim upward. Two other messenger substances caused the opposite to happen. The cilia stopped beating, and the microscopic animals began to sink. The neuropeptides not only guided the larvae up or down the column; they also controlled the extent to which they changed their position.

FROM A SINGLE CELL TO BEHAVIOR

“This means than we can observe individual cells translating a stimulus into a behavioral change,” says Jékely, summarizing the significance of these experimental results. In mice and humans, this is much more complicated, due to the huge number of links involved. There is, as it were, a black box between the incoming and outgoing signals.

In ragworm larvae, on the other hand, the researchers already have a fairly accurate idea of this black box. They therefore want to investigate the function of the individual nerve cell types step by step, so that they can work out the interrelationships of the worms’ entire nervous system. And once the simple system of Platynereis dumerilii has been decoded, its basic principles can also be extrapolated to the complex networks of the higher animals.

However, the work of these scientists is not only of significance to neurobiology, developmental biology and evolution research. These findings also benefit zoologists, marine biologists and, in particular, the field of marine ecology. After all, a great variety of invertebrate organisms that live on the ocean floor go through a developmen-
The Max Planck scientists are thus at the interface between different biological disciplines. They aim to develop the ragworm and its larvae into a model organism as powerful as mice, fruit flies and the roundworm Caenorhabditis elegans. “So far, there are only eight or ten groups in the world working with Platynereis,” says Gáspár Jékely. Because of this, and unlike colleagues who work with standard experimental animals, they do not have access to an exhaustive supply of molecular biology tools.

“We first have to develop methods for many of our experiments, but the range of options is constantly becoming broader,” says Jékely. And the biologist is convinced that, bit by bit, more and more scientists will recognize what a fascinating lab animal Platynereis dumerilii really is.

**TO THE POINT**

- The ragworm Platynereis dumerilii, with its simple sensory and nervous system, can be used for research into how sensory stimuli induce behavioral reactions, and how eyes and nervous systems have evolved.
- With the aid of just one light-sensing cell on each side of its body, directly linked to a wreath-like ciliary band for locomotion, the ragworm larva can use its spiraling movements to swim accurately toward a light source.
- Environmental stimuli guide the worm larvae’s behavior, with various neuropeptides acting as messenger substances in this process.
The idea comes directly from medical practice – or more precisely, from the South West UK Children’s Burn Centre in Bristol, where pediatrician Amber Young treats hundreds of children with burn and scald injuries every year. And every year, the number of children seeking treatment increases. The cause of their injuries is often, for example, a boiling-hot cup of tea or coffee that the children tried to retrieve from an unreachable kitchen counter. Time and again, the parents end up returning to the hospital with the children after they have been discharged because the young patients have developed a high temperature. This may be a harmless immune reaction, but it can also be a sign of a bacterial infection that may prove fatal if the dressing is not removed and further treatment administered. The doctors can only guess, and face a difficult decision based on this: change the dressing or not? Changing the dressing means torture for the young patients – something the doctor would really rather not have to inflict.

INNOVATIVE DRESSINGS AS AN INFECTION INDICATOR

Amber Young wondered whether it might not be possible for researchers to develop a dressing that would reliably indicate whether an infection had set in. Or, even better, a dressing that would treat the infection before it can become established and force the child to return to the hospital.

The pediatrician’s request found its way to the chemists working on the EmbeK1 and BacterioSafe EU research projects, which are coordinated by Renate Förch from the Max Planck Institute for Polymer Research in Mainz. The scientist’s previous work involved the application of printable coatings to plastic cups and bags and technical textiles. Plastics also play an important role in her new research field: “Plastic bags and wound dressings are often made of the same material,” says Förch. Although they look and feel different, they both consist of such materials as polypropylene, polyester and nylon.

As part of the BacterioSafe project, the researchers are developing quasi-intelligent dressings and bandages that can indicate that a wound is infected...
Dressing without bacterial protection: Burns are treated using Smith & Nephew’s Biobrane dressing. The researchers from the BacteriaSafe project are developing a dressing that prevents, or at least indicates, bacterial infections.
A NANO-LAYER STIMULATES CELL GROWTH

The Mainz-based scientists have already produced the first coatings, for example for titanium plates used by physicians to treat bone fractures. The scientists have even succeeded in coating the screws with which the plates are attached to the bone with a nanometer-thin polymer layer that has zinc nanoparticles embedded in it. The method used to apply this coating is called the plasma process. “It can be used to coat any three-dimensional structure,” explains Förch.

Doctoral student Martin Heller demonstrates how the plasma process works. He turns a valve that connects a pear-shaped glass flask with a much larger glass tube around which a cable is wound in a regular spiral. The latter contains a small titanium screw that is to be coated. “Molecules known as monomers are now streaming out of the small flask into the bigger one,” says Martin Heller. He then turns a regulator. “And now I’m setting it at 100 watts.” Alternating current now flows through the spiral, such that an alternating electric field activates the molecules inside the larger flask. The field removes electrons from the molecules, leading to a mixture of charged particles and electrons: a plasma. “The ions are highly reactive due to the loss of electrons,” says Heller. The alternating field also activates the surface of the screw, so that this, too, becomes reactive. As a result, molecules bond to the surface and react further with mole-

by releasing dyes. What’s more, they can kill bacteria through the targeted release of antibacterial substances. Renate Förch firmly believes that this can be achieved with the help of nanotechnology. Therefore, although the BacterioSafe researchers are pursuing Amber Young’s objective – the pediatrician is also a member of the consortium – the problem that the group would also like to contribute to resolving goes much deeper: the fact that the traditional weapons against bacterial infection, antibiotics, are becoming less and less effective.

NEW WEAPONS FOR FIGHTING RESISTANT PATHOGENS

The hospital-acquired infections Staphylococcus aureus and Pseudomonas aeruginosa, which infest healing injuries and clinical wounds and cause infections, are a particular cause for concern. Almost one-third of bacterial strains are resistant to antibiotics. The German Society for Hospital Hygiene (DGKH) estimates that, in Germany alone, such resistance costs the lives of 30,000 patients annually. The pathogens are also introduced to patients through implants. For example, some patients with artificial hip joints have to endure several operations due to bacterial infections at the site of the implant.

“We need new weapons against resistant pathogens,” summarizes Förch. “If possible, weapons that kill infections at their onset.” What the researcher has in mind are materials or implants with coatings that release antibacterial substances in the early stages of an infection.

The substance favored by the Mainz researchers is zinc. As part of the Embek1 project, the team developed a polymer coating that releases the heavy metal. “Heavy metals are a potent weapon against bacteria,” says Renate Förch. Silver and zinc kill bacteria and are thus good candidates for spearheads in the war against hospital pathogens. Zinc is particularly suitable, as the heavy metal has a concentration range in which it is toxic to bacteria but not to humans – even after prolonged application. Zinc also has a clear price advantage over silver. However, it remains to be clarified whether the long-term use of zinc eventually leads to resistance.

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cules from the gas phase, gradually forming a thin surface coating. The monomers consist of a complex compound in which organic molecules surround a zinc ion. The alternating field dissociates the molecules into different reactive components. The organic components bond to form a network of molecular chains, like in a polymer; in this case, however, the chains are of different lengths and form an irregular network of polymer-like molecules called a plasma polymer. The zinc is embedded in its meshes in the form of nanoparticles.

“We also opted for the plasma process because it has already been in use in industry for decades, for example for the modification of polymer webs,” says Renate Förch. “From the outset, we placed particular emphasis on the practical applicability of our developments.” The researchers in Mainz have also proven that the coatings actually have an antimicrobial effect. They applied a zinc-containing coating in a thickness of 500 nanometers (millionths of a millimeter) to cell culture dishes and seeded the hospital pathogen *Staphylococcus aureus* on them. The bacteria were all killed. In a control experiment, the microorganisms thrived on a control dish with no zinc coating.

**HOLLOW SPHERES RELEASE ACTIVE SUBSTANCES**

The researchers also tested the effect on human cells. An implant or dressing that could kill harmful bacteria but that would simultaneously damage the patient’s cells would be useless. Therefore, Renate Förch’s team tested whether the antibacterial coating inhibits the growth of the endothelial cells, which play a crucial role in wound healing. Initially, this proved to be the case – a setback.

However, the researchers managed to find a solution to this problem. They added another layer, this time just 15 nanometers thick. It consisted of plasma-polymerized allylamine (ppAA), which has been shown to be biocompatible. The endothelial cells grew even better on this coating than on a base consisting of unmodified titanium.

The scientists solved two problems with this additional coating. Without a coating, the zinc reservoir emptied itself within a period of 24 hours. This period is often too short for practical applications: “Surgeons tell us that the reservoir should last two weeks,” says Förch. The wound needs this long to heal following implantation, and the increased risk of infection also lasts this long. The biocompatible top layer delayed the release of the zinc. “By modifying the thickness of the coating, we are able to control the release period to one, two or three weeks dur-
ing which the zinc is to be released,” says Renate Förch.

In any case, the chemists are pursuing the idea of producing multifunctional coatings by layering several coatings. The ideal coating should not only release zinc over a specified period, but also act as a sensor that detects the presence of harmful bacteria and releases the active substance only if they are present. At the same time, it must promote the growth of the body’s tissue, and thus wound healing, as well. Moreover, the coating of implants should be such that it either enables or disables biointegration – depending on whether the implant is intended to remain in the body or to be removed at a later stage.

Renate Förch explains why the latter option is sometimes desirable: “In the case of a wrist fracture, a titanium plate must be implanted, but only for a few weeks.” The doctor then has to stand in the operating room for hours, cutting out the implant that has by then been integrated into the tissue, and creating a new wound in the pro-

The ideal coating should act like a sensor.
cess. Förch’s team is currently working on a coating that will prevent the integration of titanium implants into body tissue. “This coating will contain a chemical compound containing silicon and oxygen.”

ENCAPSULATED ACTIVE SUBSTANCES FROM DEGRADABLE BIOPOLYMERS

There are also examples in which the integration of implants is desirable: Eye implants for the treatment of glaucoma consist of polymer materials and are required not to interact with the tissue, despite the fact that they are intended to remain there permanently. The organism treats them as foreign objects and encapsulates them by surrounding them with a layer of connective tissue. When this happens, the implant, whose purpose is to regulate the internal eye pressure, no longer functions. The Mainz-based researchers aim to change this by applying a polymer coating to the implants, the chemical structure of which resembles natural biological material.

In the meantime, Martin Heller is testing the practical suitability of the zinc coatings on the implant screws. “The layers must not increase the diameter of the screws perceptibly,” explains the biologist. He has procured the thigh bone of a pig, because pig bones are very similar to human bones in terms of their solidity. Using a surgical screw driver, he screws an almost one-centimeter long screw into the bone and back out again. He then examines it under the electron microscope for scratches and abrasions, and tests whether the coating was damaged during the process.

Renate Förch hopes that the first products based on the new technology will be available in five to ten years. The need for them already exists, as evidenced by an e-mail she recently received in which a woman enquires about the findings of the Embek1 study. Her husband, who has an artificial hip joint, has undergone three hip operations and has suffered from repeated infections. “We also often receive inquiries from industry,” says Förch. Although the Embek1 project has been completed, the team continues to carry out research on the coatings for implants and dressings.

They are also working on the BacterioSafe project. “We are re-inventing the Trojan horse at the nano-level,” says Renate Förch. The Trojans to be outwitted in this case are the hospital-acquired infections. The Trojan horse consists of nanocapsules, hollow spheres with a diameter of around 150 to 400 nanometers, which Katharina Landfester, Director at the Max Planck Institute in Mainz, is developing with her team. The researchers attach the spheres to a polypropylene non-woven, which acts as the basis for a dressing. The role of the soldiers hidden inside the horse is assumed by antimicrobial substances or antiseptics, which are locked inside the nanocapsules.

Although the hospital bugs don’t perceive the nanocapsules as a gift, they are outwitted by them. Because the capsules have a shell that consists...
of naturally occurring polymers, such as polylactic acid, to the harmful bacteria, they look like natural components of the body. Due to this mistaken identity, the hospital infections channel their aggression against the capsules.

The bacteria secrete toxins and enzymes that would normally attack the cells of the infected tissue. Typical examples are lipases, which readily digest the lipid membrane of healthy cells. This is usually observed in the form of damaged tissue around the site of infection. The substances released by the bacteria also digest the shells of the nanocapsules. The damaged containers then release their contents into the environment, and the antimicrobial substances are liberated.

It is intended to use this effect for different functions in innovative dressings coated with nanocapsules. “First, a dressing equipped with nanocapsules could indicate an infection through the release of a dye by the capsule,” says Renate Förch. Doctors like Amber Young could then be certain that a patient actually has a bacterial infection before subjecting him or her to the torture of changing the dressing. Second, an antimicrobial or another active substance that kills bacteria could flow out of the capsule and attack the pathogens directly. And third, an active substance could also be released that supports the regrowth of healthy tissue.

The BacterioSafe researchers have already demonstrated two of the functions using prototype dressings. For the first function, the capsules release a dye when their shells have been digested, as the researchers working with Toby A. Jenkins from the University of Bath demonstrated.

MATERIALS AND PROCESSES FOR INDUSTRIAL PRODUCTION

The British team is also part of the BacterioSafe consortium and also demonstrated the second function: In the experiment, the dangerous hospital bugs actually broke into the nanocapsules, but the comparatively harmless intestinal bacteria Escherichia coli were unable to do any damage to the capsules. That was good for them, as the capsules contained the antimicrobial substance sodium azide. The aggressive hospital pathogens, in contrast, did fall victim to this substance in the experiment. “The experiment showed that the active substances are released only when they are actually needed,” explains Jenkins. In his view, this could result in the more directed use of antimicrobials or antibiotics and thus reduce the risk of antibiotic-resistant pathogens.

At the Max Planck Institute for Polymer Research, Katharina Landfester’s team is developing other variants of the nanocapsules. Their shells consist of different biological molecules, polylactic acid or hyaluronic acid, which combine to form a polymer-like network. The shells thus consist of degradable bioplastic.

“Predetermined breaking points are broken down by the bacterial enzymes,” explains Landfester. Hyaluronic acid is such a predetermined breaking point: it is broken down by a particular enzyme called hyaluronidase. “The most important strains of the hospital bugs secrete this enzyme in high concentrations,” explains the Max Planck researcher. Therefore, the use of a hyaluronic acid shell is very promising.

Nonetheless, the scientists are testing capsules made of different materials and have a good reason for doing so. First, not every drug can be locked into every shell; for example, a hydrophilic drug needs a hydrophilic shell. Moreover, the researchers are generating a pool of knowledge about the production and properties of different kinds of nanocapsules and finding the answers to a series of questions: How stable are the nanocapsules? Can they be exposed to air or do they have to be stored in water? Can they survive in the conditions that prevail in hot countries?

In addition, different shells can be used for multifunctional dressing materials. If one capsule is placed inside another, like a Russian matryoshka doll, according to Landfester, it is possible
to trigger a two-stage reaction to an infection. Thus, a dye contained in the external capsule could be released first, followed by an antibiotic contained in the inner capsule.

However, the first task is to look for suitable nanocapsules. “After 18 months’ work on the project we have already developed 13 systems, some of which appear to be promising,” says project leader Förch. “And the issue of practicality is always at the back of our minds.” For example, the scientists use only substances that have been authorized by the US Food and Drug Administration (FDA) for the shells.

The know-how relating to coating using the plasma process is also proving essential for the development of dressings with nanocapsules, as the minute spheres must be firmly attached to the dressing. “To this end, we coat the dressing material in such a way that individual chemical groups protrude like little trees from the earth,” explains Renate Förch. The nanocapsules can also be made in such a way that reactive groups protrude from them like anchors. These chemical anchors bond with the surface functional groups and fuse the capsule with the surface of the dressing.

“The materials and processes that we select for this coating are suitable for production on an industrial scale,” says Förch. “Our aim is to achieve functioning demonstrators.” The chemist freely admits that striking this balance between basic and applied research is not always easy. A requirement of EU-funded research projects is that they generate added value for society, so they must have potential feasibility.

On the one hand, the scientists in Mainz are generating basic knowledge about innovative intelligent dressings and implants; on the other hand, they are ensuring that the results of their research will not be left collecting dust in a drawer. Förch’s success with research applications for the EU, which is particularly critical in this regard, is evidence of the fact that their concepts are suitable for achieving this balance: “On average, 90 to 95 percent of applications fail the evaluation. We have been successful with all three of the applications we have submitted to date.” Thus, the chances that Amber Young’s wish for an intelligent burn dressing will be fulfilled are looking good.

TO THE POINT

- Multi-resistant pathogens often cause fatal infections in operation wounds, healing injuries and implants.
- In the EU projects Embek1 and BacterioSafe, scientists are developing intelligent medical dressings. These are aimed at indicating the presence of infection in a wound by releasing dyes, and killing bacteria through the targeted release of antimicrobial substances.
- The scientists use the plasma process to develop thin coatings for implants, or they package their weapons for fighting the pathogens in nanocapsules.
This snapshot shows the ocean currents at a depth of 75 meters, as simulated by the global ocean model MPI-OM TP6M. The very high resolution with grid spacing of 10 kilometers enables good resolution of the swirling turbulence of the Gulf Stream, an important part of the Atlantic Overturning Circulation. This simulation was performed as part of the STORM project.
Climate Memory

A gigantic heat pump is at work in the Atlantic Ocean, pushing tropical waters north and supplying Europe with a pleasantly warm climate. Jochem Marotzke, Director at Hamburg’s Max Planck Institute for Meteorology, analyzed this current, laying the foundation for an improved climate model.

TEXT NICOLA WETTMARSHAUSEN

Upon hearing the word “ocean”, most people think of diving or sailing, of beaches and vast expanses. Jochem Marotzke, however, sees something very different in his mind’s eye: an enormous current of water. It starts at the equator, where warm masses of water roll off to high northern latitudes, then cool down, sink and flow slowly south once more as cold deep water.

The Atlantic Meridional Overturning Circulation (AMOC), as scientists call it, is part of an enormous band of currents that flow through all of the world’s oceans. As they travel, the ocean currents convey huge amounts of heat from one region to another, thus significantly influencing the climate.

Jochem Marotzke’s research revolves around these ocean currents. The Director at Hamburg’s Max Planck Institute for Meteorology has been working for years on AMOC prediction, with an ultimate view to creating a perfect climate model.

“If we don’t understand the processes in the ocean, we won’t succeed in modeling the climate,” he says, and describes the atmosphere as a “transient something” that can’t conserve states over long periods of time. Temperature and pressure can change at breakneck speed in the air. However, since water has a high heat capacity, it can store heat for longer. As a result, the ocean reacts much more sluggishly to change than the atmosphere. This is why physicist Jochem Marotzke refers to it as “climate memory.”

CURRENT FLUCTUATIONS INFLUENCE THE CLIMATE

The AMOC is an enormous phenomenon, with an average of 18 million cubic meters of water per second circulating through the 7,000-kilometer-wide Atlantic basin. However, its strength can fluctuate hugely in the course of a single year, sometimes transporting more than 30 million cubic meters of water, and sometimes just 10 million.
This is due to seasonal winds, whose impact on the sluggish ocean currents is delayed by several months. But the current can also vary considerably within a single month or even a day. These strong fluctuations make it difficult to determine the strength of the AMOC.

Scientists have long been trying to predict the changes in the AMOC, and thus the climate itself, for five to ten years into the future. All these attempts have had little success, but Jochem Marotzke’s team wants to change that. The fact is, the AMOC is important not only for Europe; its fluctuations also influence droughts in the Sahel and hurricane activity in the North Atlantic, even more than previously thought.

In order to make scientifically sound predictions, the researchers first needed real data to check whether their model correctly simulates reality. But how does one measure currents in an ocean that is 7,000 kilometers wide? Jochem Marotzke has a solution: “We simply break down the AMOC at 26.5 degrees north into three different components.”

OLD PHONE CABLES MEASURE CURRENTS

To start, the scientists consider the 100-kilometer-wide Gulf Stream, which runs north through the Florida Straits. This is the fastest-flowing current. The second component is the Ekman current in the top 100 meters of the ocean, dominated by the wind and the Coriolis force. Most important, however, is the mid-ocean current, which lies below the Ekman current at a depth of 100 to 1,000 meters, and extends across the entire width of the Atlantic basin. “First we measure all three components separately, and later we add the values together,” explains Marotzke.

The latitude of 26.5 degrees north was not chosen by chance – some data series are already available here. Changes in the wind-driven Ekman current, for example, have been recorded directly by QuikSCAT since the 1990s. This satellite scans the surface of the ocean using microwave technology, yielding information on surface waves and wind strength.

Data is also available on the Gulf Stream in the Florida Straits; the Gulf Stream is measured using old telephone cables that lie on the ocean floor. “It’s a clever method,” finds Daniela Matei, a researcher in Marotzke’s department. “The procedure is based on the fact that the salt ions in the water flow downstream, moving through the Earth’s magnetic field and thus generating an electrical field. This field induces in the submarine cables a voltage that is logged at regular intervals.” American scientists have been gathering this data since 1982 and making it available to their colleagues all over the world.

So far, it’s all relatively simple – we’re not for one small problem. For now, there are no long data series for the large mid-ocean current; only sporadic...
measurements taken by ships. “The ships took six weeks to cross the Atlantic just once,” says Jochem Marotzke. “The crew took measurements several times a day during the crossing, but of course no data is available for the period before or after that.” Besides, he adds, such research expeditions are extremely expensive and therefore not regularly undertaken.

DEEP CURRENTS THROUGH DENSITY DIFFERENCES

At that time, Marotzke, as a climate modeler and theoretician, found himself with no other option than to gather the necessary data himself. With this in mind, he started the RAPID/MOCHA project with British and American colleagues in 2003, when he was working at the National Oceanography Centre, Southampton (NOCS). “I wanted not only to collect data on an ongoing basis, but also to develop the prototype for a new monitoring system,” explains Marotzke. “Only by doing this can we truly scrutinize the AMOC in the next ten years.”

He put out to sea as early as 2004, and on the first voyage, he and his colleagues anchored 19 measuring probes along the 26.5 degrees north latitude line in the Atlantic basin. At depths of up to 5,000 meters, the probes recorded temperature, salinity, and current speed and direction. They now record a vertical profile of density right across the ocean depths, thanks to the four-year campaign.
“Now we had a good stock of basic data,” says Johanna Baehr of the University of Hamburg, who has been working on the analysis with Jochem Marotzke and Daniela Matei since 2008. The team used the density measurements to calculate the strength of the AMOC. “Seawater has different densities depending on the temperature and salinity of the water,” explains Baehr. This leads to differences in density, and thus pressure, in the ocean. Since water always tries to flow toward a point of lower pressure, the pressure differences generate a current. The team was able to calculate the velocity of this current using the measurements taken from the whole width and depth of the Atlantic, from the Bahamas to the coast of Africa, at 26.5 degrees north. This gave the scientists an accurate picture of the fluctuations in Atlantic circulation between 2004 and 2008.

They then calculated the AMOC fluctuations for the same period in a computer simulation and compared these results with the real measurements. This yielded a “hindcast” – a retrospective prediction that is used to test the quality of a model.

The researchers used the coupled atmosphere-ocean-climate model ECHAM5-MPI-OM for their simulation. It was developed at the Max Planck Institute for Meteorology and used for the climate scenarios of the Intergovernmental Panel on Climate Change (IPCC). Scientists use ECHAM5 to simulate processes in the atmosphere, and MPI-OM to simulate processes in the ocean. The two models are usually coupled together so that the simulated atmosphere influences the behavior of the ocean model and vice versa.

REAL DATA MAKE THE MODEL MORE PRECISE

However, Daniela Matei modified the program and fed real atmospheric data into the ocean simulation on an ongoing basis, with wind and air pressure values gathered by the National Centers for Environmental Prediction (NCEP) over the course of 50 years. This showed that integrating real wind values does bring the ocean simulation much closer to reality – but is the newly programmed model really so good that it can look into the future?

In the German Climate Computing Center, the processors worked away for weeks and months, finally revealing that the improved ocean-climate model is sound and delivers on its promises. “There is very reasonable agreement between the measured data and the calculated data; the hindcast comparison looks good,” announces Jochem Marotzke with pride. “These new climate model calculations enabled us to predict the North Atlantic circulation accurately for the first time, and that for short periods of up to four years into the future.” Such short forecasts are much more difficult to generate than longer-term prognoses stretching toward the year 2100, because values are averaged out for long-term prognoses, so the curves become smoother. This permits the detection of longer-term trends, such as the weakening of the AMOC described by the Intergovern-

The red line shows the measured flow volume of the Atlantic Meridional Overturning Circulation (AMOC). The prediction (blue) shows that the AMOC will remain stable until 2014 (light blue: ensemble of several calculations; dark blue: mean value).

In the long term, global warming will weaken the AMOC. The red and orange lines represent its development if human influence on climate is moderate, while the blue lines reflect strong human influence. The black line predicts how the AMOC would develop in the absence of any human impact on climate.
Keeping an eye on the near future: Johanna Baehr, Jochem Marotzke and Daniela Matei are interested in climate change over the next ten years.

So what is the prediction for the AMOC? “Despite all the naysayers, the strength of the Atlantic Overturning Circulation will remain stable,” says Marotzke. “We can also now say with confidence that the weakening of the Atlantic circulation in March 2010 was only a short-term phenomenon.”

Some people saw that weakening as an omen of a lasting reduction in the AMOC’s strength, which is still discussed as a possible consequence of climate change. A scenario such as that seen in Roland Emmerich’s film *The Day After Tomorrow*, in which the AMOC peters out entirely and the Northern hemisphere freezes under a thick layer of ice, will not happen, Marotzke is certain – “at least not before 2014.”

**TO THE POINT**

- The Atlantic Meridional Overturning Circulation (AMOC) conveys huge amounts of heat from one region to another, thus significantly influencing Europe’s climate.
- Understanding the AMOC is vital for reliable climate modeling.
- Max Planck scientists accurately predicted this North Atlantic current, concluding that it will remain stable until at least 2014.

**GLOSSARY**

**Coriolis force:** The Coriolis force plays an important role in physical oceanography. Water masses operate in a rotating frame of reference, due to the rotation of the Earth. Those located in the northern hemisphere are deflected toward the right, and those in the southern hemisphere toward the left. The influence of the Coriolis force also gives rise to areas of high and low pressure in the atmosphere.

**German Climate Computing Center (DKRZ):** The DKRZ is the virtual laboratory of all German climatologists who use climate modeling as the basis for their research. The accuracy of a climate model depends on the performance of the supercomputer, but is also limited by it. This is partly due to the complexity and dynamics of climate, and partly to the enormous quantity of data that must be calculated and analyzed. The DKRZ is one of the world’s most important computing centers for climate simulations. Its data archive currently holds a volume of 20 Petabytes, and this increases with each new generation of computers.

**RAPID/MOCHA project:** Following the first phase from 2004 to 2008, the AMOC is being monitored under the RAPID-WATCH project until 2014. The continuous monitoring over the course of ten years is important for the constant adjustment and improvement of the MPI Ocean Model.
Dirty deals: Bribery, kickbacks and corruption are widespread in many countries. The lowest incidence is in New Zealand. On a global scale, Germany ranks 14th, with Somalia at the bottom of the list, in 182nd place.

Every legal system in the world punishes corruption – but the punishments vary widely. The “how” is something that Christoph Engel, Director at the Max Planck Institute for Research on Collective Goods, and his colleagues Sebastian Goerg and Gaoneng Yu are studying in a laboratory experiment at two universities in Germany and China.

When a civil servant accepts a bribe, it is more a serious offense than when a citizen attempts to gain an advantage through bribery. This is because the civil servant, as an employee of the state, is abusing the powers that state vested in him. This, at least, is the thinking embodied in many criminal law codes. Offering bribes in these countries does not go unpunished, but the punishment is less severe than that meted out for taking a bribe.

German law takes a different view, promising equal penalties for both parties to a corrupt act. Should German law learn a lesson from such countries as Russia and China? Should German judges at least fully exploit the range of penalties when sentencing the civil servant? “If it were only a question of finding a penalty to match the crime, that would be fine,” says Christoph Engel. But criminal law is not only backward-looking, aiming to find a justified sanction. It also serves the forward-looking purpose of preventing future crime.

What can the law expect when both parties to an illegal deal are aware that, if the public prosecutor catches up with them, they will face different penalties? “If both of them are only out to make as much money as possible, nothing will change,” says Engel. “But human beings are not money-making machines. When they feel cheated, many of them have a desire for revenge.” In fact, it was this train of thought that led the scientist to translate the difference between legal systems into a game to be tested in the laboratory.

Some of those who took part in the game must have been reminded of a Disney cartoon script when they read the instructions. The money given to them to
Playing at corruption: In an experiment, scientists studied how 96 students at the Universities of Bonn and Shanghai played out corrupt scenarios under differing punishment schemes. In 11 rounds of the game, each player was placed in the position of pretending to either procure a corrupt act or receive a bribe for committing one.

The scientists were primarily interested in whether symmetric and asymmetric punishments have differing effects in persuading potential parties to a corrupt act to make or accept an offer, demonstrate their gratitude or turn themselves in if a bribe was accepted but the corresponding consideration failed to materialize.

The bribe-giver received triple the stake

Their partners – the game was always played in pairs – were given 60 talers to start with. At the end of the experiment, the scientists cashed in the play money for real money. “This is important in order to provide credible incentives,” says economist Sebastian Goerg, who oversaw implementation of the experiments at the BonnEconLab in Germany and the Vernon-Smith Experimental Economics Research Center in China.

He describes the basic idea as follows: “Depending on skill and luck, the participants could increase their pot of money provided that, by offering a payment of 40 talers, the proactive players were able to persuade their partners to do them an unlawful favor.” The reactive player then had two choices: reject the money or accept it.

If he or she decided to accept the offer, they again had two options: do the proactive player a favor, or pocket the money without doing anything in return. In the latter case, their partner not only lost the 40 talers, but they received nothing from the bank, either. “However, the loser did have the opportunity to punish the untrustworthy partner,” explains Sebastian Goerg.

If the player who was cheated, having first played in discrete silence, now publicly announced what had happened, a fine was imposed on the other player, as well as on the one who was cheated. However, even if both parties were agreed on the deal, the prospect of quietly making money through mutual accommodation was offset by a further risk of punishment.

Another risk factor was introduced into the game by random generator, Goerg explains: “There was a 25 percent probability of players losing part of their cash.” If the deal was nevertheless concluded, not only did the recipient of the bribe make a profit of 40 talers, but the giver of the bribe received three times the stake as a “favor” from the bank.

After the first round, the participants discovered that they were then to play ten more rounds with the same partner. And after each round, the researchers updated the players on the decisions made and the balance on their account. They weren’t, of course, interested in who went home with the biggest profit. “We wanted to study the punishment mechanism,” says Sebastian Goerg, explaining the meaning of the games in the laboratory.

LABORATORY TESTS IN DIFFERING CULTURAL ENVIRONMENTS

The scientists were primarily interested in whether symmetric and asymmetric punishments have differing effects in persuading potential parties to a corrupt act to make or accept an offer, demonstrate their gratitude or turn themselves in if a bribe was accepted but the corresponding consideration failed to materialize.
In picking Bonn and Shanghai, the researchers chose locations for the experiments that were distinguished by differing cultures and legal systems. The German legal system, along with those of France, the UK and the US, is one of the major systems to rely – at least in the letter of the law – on the symmetrical punishment of corruption, with both parties to an illegal act being punished equally.

By contrast, in countries such as China, Russia and Japan, the belief prevails that “giving is less evil than taking,” at least as far as the law is concerned: their legislation follows an asymmetrical approach. The penalties for those who purchase the goodwill of another through gifts or favors are less than those meted out to the recipient. Christoph Engel sees two arguments that underpin the propensity of this system to let the giver of a bribe off more lightly than one who accepts it. “First, it has to do with perceptions of right and wrong, and morality. Bribery isn’t just an economic crime, it is also a breach of honesty and integrity.” Holders of public office – to whom most potential bribes are generally offered – are deemed to have accepted their position of their own free will, and with it the particular obligations it entails. So breaching these obligations by accepting a benefit of some kind is considered to be especially serious.

The second argument is purely pragmatic: the party offering a bribe is seen as the weaker party to the transaction, since he is in a less advantageous position. From this perspective, the asymmetric system offers an element of revenge in the event that the official should pocket the bribe but refuse the consideration in return.
Given the number of cases that go unreported, it is impossible in real life to adequately investigate which of the two systems constitutes the better strategy in the fight against bribery, kickbacks and other forms of corruption. “In our experiment, in contrast, we have all of the factors under control, and we can exclude any influences that are not central to the issue,” Christoph Engel says, explaining the unbeatable advantage of laboratory games with ta- 
lers and random generator.

THE RANDOM GENERATOR COMES INTO PLAY

In their experiment with 96 students from the Universities of Bonn and Shanghai, the researchers varied only the systems of punishment, while all other factors remained constant. In the asymmetric round of the game, the giver of the bribe lost 10 talers and the recipient 50 when the random generator applied the punishment mechanism. In the symmetric version, in contrast, both parties were fined 50 talers when this happened.

This procedure enabled the researchers to study the effects of both punishment systems on the player’s behavior by comparing the frequency of attempted bribes, considerations performed in return and players turning themselves in. “A laboratory experiment is more meaningful because you 
can turn the individual cogs of the complex construct of the legal system as a whole and immediately see wheth-
er anything has changed, and if so, what,” says Sebastian Goerg. “In this sense, our work is similar to that of physicists.”

However, the experiment was also affected by a peculiar paradox of hu-
man behavior. Because from a purely rational perspective, bribery ought not to exist – not, at least, if the players’ be-
havior is aimed exclusively at maximizing their own benefits. And that is a ba-
sic assumption of game theory. “On this basis, no one would dream of re-
porting what had happened, even if the consideration were not performed in 
return,” says Christoph Engel, citing the primacy of reason. “A bribe offerer who is interested solely in maximizing their profit would never report the at-
tempt just for revenge.”

After all, it would reduce their prof-
it because they, too, would be penal-
ized. Seen from this point of view, it shouldn’t matter whether the penalty paid by the offerer is high, as in a sym-
metric system, or relatively low, as in an asymmetric system. A rational recip-
ient acting on the same principle would foresee the other party’s behavior and accept the offer without performing the consideration.

The recipient makes a profit simply by acceding to the attempt at bribery and need have no fear that the other party will turn themselves in – because
doing so would compound their loss. “Since, however, under these conditions, a rational offerer of a bribe would recognize the logic, they wouldn’t make the offer in the first place,” Christoph Engel explains. “Consequently, under both systems, there ought not to be any attempts at bribery.”

One look at the media, however, shows that, in reality, this is not the case. Not least the annual reports by the independent anti-corruption organization Transparency International serve to prove the point. In fact, bribery of every kind appears to be an international phenomenon – but with varying characteristics.

Transparency International regularly publishes league tables depicting the level of corruption in various countries around the globe. In the current table, in which New Zealand occupies first place with the lowest level of discovered corruption cases, Germany ranks 14th and China 75th. Lowest-placed is Somalia, at 182.

It is evident that reason is not alone in playing a role. For example, the fact that people are willing to accept some disadvantage to themselves if, in doing so, they can inflict punishment for unfair conduct has regularly been observed in various experiments, and was also in evidence in the bribery games in Bonn. “As we surmised, symmetric and asymmetric systems of punishment had differing effects on the players’ behavior,” says Sebastian Goerg, summing up an observation that is likely to be of interest not only to scientists at the institute in Bonn.

Both in Shanghai and in Bonn, under asymmetric conditions, far more players confessed their guilt rather than simply writing off the 40 talers invested in an uncooperative partner. Of those who offered bribes, 55 percent in Bonn and 69 percent in Shanghai decided to make public a transaction that, from their perspective, had failed. Under symmetric conditions, the proportions were substantially lower, at 29 and 27 percent.

**LAWMAKERS ARE OFTEN VAGUE IN SPECIFYING PENALTIES**

One positive effect of the unequal punishments was a lower propensity on the part of recipients to run such a risk. “Under asymmetric conditions, far more offers were rejected,” says Goerg. At first sight, this result would indicate that this is the better strategy in the fight against corruption.

However, there were also parallel increases in the number of attempts at bribery, as well as in the number of “cash for favors” transactions completed. Having accepted an offer, 80 percent reciprocated when the other player was due to receive a lower penalty if they confessed; under symmetric rules of punishment, the figure was less than half of those offered a bribe.

“If the situation we investigated goes to the core of the interaction between those who offer bribes and those who hold public office, the message for politicians is clear: lower penalties for offering bribes lead to more corruption,” says Max Planck Director Christoph Engel. This, he warns, is something that especially those should
be aware of who, in a nominally symmetric system, tend in practice toward an opposite interpretation. In most countries, lawmakers merely set upper and lower limits, without precisely specifying actual punishments. “The courts like to exploit this lack of precision to covertly adopt an asymmetric approach.”

RISK-TAKING IS COLORED BY TIME AND EXPERIENCE

Not least in view of the results of the laboratory games, Christoph Engel doesn’t consider this to be a good idea. Under such circumstances, interested parties would have fewer inhibitions about contacting civil servants and offering a financial inducement to violate their official obligations. Asymmetry is also likely to lead to more stable partnerships in corruption, since doubtful candidates would not get involved in the first place.

In the experiment, time and experience emerged as two important factors that strongly influenced the participants’ appetite for risk. The researchers noted that, rather than establish a strategy from the beginning, players in Shanghai and in Bonn developed their approach as the game went on. And in both locations, they observed that the more experienced the players became, the more cautiously they behaved.

If their attempts at bribery were, from their perspective, successful, the proactive players continued to make enticing offers to their partners. If, on the other hand, they had been punished in the past, they were far more reticent in making offers in subsequent rounds. It was evident, too, that those who had inflicted punishment on a partner who cheated them had no qualms in expecting others to do the same. When switching to the role of recipient, they frequently either declined a risky offer or played their part to the benefit of the offerer.

Under symmetric conditions, in contrast, corruption declined significantly from round to round in both China and Germany. “To us, this is an indicator of a generally applicable effect that is not influenced by social, political, economic, legal or cultural conditions,” says Christoph Engel. Of course the researchers weren’t able to incorporate the same draconian penalties in the game as may apply in corruption cases in real life – from country to country, the spectrum ranges from loss of employment to exclusion from the community to the death penalty. “But the players certainly felt the financial penalties. They were meant to hurt,” says Goerg.

In the end, however, the results showed that both strategies have their advantages and disadvantages. “Our recommendation to politicians is the usual lawyer’s qualification: it all depends,” says Christoph Engel, himself a legal expert. Nor is his colleague and co-author Sebastian Goerg too keen on handing out concrete advice.

He can’t, however, resist offering one tip for China’s lawmakers to bear in mind: If the results of the bribery games in the laboratories in Shanghai and his home town of Bonn reflect reality – as he and his colleagues believe they actually do – lawmakers in China might consider whether they wouldn’t be better off switching to a symmetric system of punishment. “Ultimately,” says Sebastian Goerg, “our experiment has shown that an asymmetric assignment of sanctions generally doesn’t work any better among Chinese subjects than it does among the citizens of Bonn.”

TO THE POINT

- In cases of bribery in Germany, both parties receive equal punishments, while in other countries, the penalties differ.
- Max Planck researchers used a game played in laboratories in Germany and in China to discover how this difference impacts the decisions of potential parties to corruption.
- Under asymmetric conditions, significantly more players voluntarily admitted their guilt and substantially more offers were refused. On the other hand, there were also increases in the number of attempts at bribery, as well as in the number of “cash for favors” transactions completed.
- One message to politicians: Lesser punishments for those who offer bribes lead to more corruption.

GLOSSARY

Bribery: Section 334 of the German Penal Code states that: “Whoever offers, promises or grants, for the person concerned or a third person, an advantage to a public official, a person under a special obligation in respect of the public service or a soldier of the Federal Armed Forces, in return for his having performed, or his performing in future, an official act, so that the person concerned has violated, or would violate, his official duties, shall be punished by imprisonment of three months to five years. In less serious cases, the sentence shall be imprisonment not exceeding two years or a fine.”

Experimental economic research: This comprises the empirical study of economic issues and employs controlled experiments to investigate the extent to which participants are acting in accordance with economic theory. Results achieved to date have helped adapt the existing image of Homo economicus with his fixation on pure personal gain and broadened economic theory with the introduction of pro-social motives, such as altruism and reciprocity.

Game theory: Game theory facilitates studies of how rational actors act and interact in strategic situations, with a primary focus on cooperation and conflict between decision makers. Such mathematical models are employed in a wide variety of research fields, including economics, evolutionary biology, political science, psychology and law.
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“Sciences are a factory for innovations, and ultimately also for new categories of knowledge.”
Lorraine Daston on the study of sources.
For some people, Ostwestfalen-Lippe is a place that marks a key turning point in their lives. Lor- raine Daston is one such person. In the early 1980s, the young American came over from Har- vard to the Center for Interdisciplin- ary Research at Bielefeld University, as part of an international team assem- bled for one year by philosophers Lorenz Krüger and Ian Hacking to re- search the history of the probabilistic revolution: how probability theory has revolutionized our lives – from weath- er forecasting to the economy – by opening up a spectrum of degrees of certainty between the two poles “true” and “false.”

Then 31 years old, Daston, who had received her doctorate in the history of science from Harvard a few years earlier, had been a junior fellow in the So- ciety of Fellows at Columbia Universi- ty in New York and was now an assistant professor at Harvard.

And then followed a year at Bielefeld. “It really was a period that changed my life in so many different ways,” she recalls.

**GERMAN TAUGHT AS A DEAD LANGUAGE**

The first culture shock was the German language. “I hadn’t expected it to be so beautiful,” says Lorraine Daston. Al- though she had learned German while studying, her teacher taught it as a dead language. In Bielefeld, she was able to speak German without any re- straints. “People in Bielefeld were real- ly kind. At the weekly market and in the stores, everyone was very welcom- ing and patient – ideal for a non-native speaker practicing the language.”

Equally patient, open-minded and capable was Lorenz Krüger, who, to- gether with Ian Hacking, managed to create a true work collective out of the diverse group of scientists from all over the world. “I loved the atmo- sphere of good will and good humor and the concept of practical wisdom – phronesis, to use Aristotle’s term – and benefited hugely from it,” says Lor- raine Daston. “It was a kind of exis- tence proof: it is possible for scholars in the humanities to work together. It was a revelation.”

After several years on the move, Daston has now lived in Germany for almost 17 years and, as Director at the Max Planck Institute for the History of Science in Berlin-Dahlem, has also gathered many young scholars around her. She sits in her office, surrounded by nothing but books, looking out over a group of old trees in the quadrangle of a modern, light-filled building. She gazes attentively at her interviewer and talks as though dictating a book: in German, naturally, with a very precise yet lively diction. She talks about her impressive career and the finer details of her work and subject with a ready wit, sprinkled with anecdotes.
and searching for correlations, without any need for explanations. For example, when cattle eat more grass in September, the winter will be a hard one,” explains Daston.

OBJECTIVITY AS A RESEARCH OBJECT

It wasn’t until the end of the 16th century that people first attempted to make a science out of this country lore and turn it into an epistemic practice capable of generating robust results. “Observationes” coalesced into a learned genre, in which doctors and astronomers in particular set down their observations. This practice subsequently spread to other human and natural sciences as well. Observation developed into a rigorous method and a concept to be reflected upon, not only by practitioners, but also by philosophers.

The researchers have compiled histories of scientific observation from the 5th to the late 20th century in a book. “We don’t claim to have exhausted this topic,” stresses Daston. “It’s more a question of trying to open up a new field of research.” Other research groups have been devoted to the history of scientific objects, objectivity and experiments. “A Max Planck institute should do something that can’t be done elsewhere. It was a privilege to help establish this institute and organize this type of non-hierarchical working group as a new way of conducting research in the humanities,” says Lorraine Daston.

Lorraine Daston adopts a very specific approach to her research. She tries to give the fundamental epistemic categories of science – such as observation, experiment, objectivity and truth – a history; categories that now seem so self-evident to us. “Sciences are a factory for innovations – not just inventions and discoveries, but also new ideas, theories, hypotheses and models. And, ultimately, a factory for new categories of knowledge,” says Daston.

Take observation, for example. No other scientific practice is more fundamental or more widely used. Daston and her colleagues have put observation itself under the microscope, discovering how and under what historical conditions it came into being, in which disciplines it first flourished and subsequently diversified. “In the ancient world, and even the Middle Ages, observation was associated primarily with sailors, shepherds and farmers. It was all about forecasting...
This is only partly true in Daston’s case. She had plans to become an astronomer when she enrolled at Harvard, and the stars still fascinate her today. In a sense, this could be said to be her destiny: her parents, who had Greek roots, named Lorraine after Urania, the Greek muse of astronomy. She was born in East Lansing, home to Michigan State University, where her father was studying for a doctorate. He went on to become a professor of psychology, so thoughts of a career in science came naturally to Daston. It was clear from an early age that she would become a scientist. It merely remained to be seen in which field.

As is common in the US, Lorraine Daston studied several subjects: mathematics, history, philosophy, and later also the history of science. “I was very lucky in that the introduction to astronomy was presented historically. I was absolutely fascinated – it was all completely new to me.” The discovery of this new discipline solved her dilemma: “I quickly realized that the history of science was the ideal answer for people like me, who can never decide whether they prefer natural sciences or humanities – or something in between. In the history of science, everything is possible.”

But there is more to it than that. You have to master a wide range of disciplines to make it work – “because history doesn’t respect current disciplinary boundaries,” as Daston says. At Harvard, she also wrote her thesis on the history of probability theory, its emergence in the 17th century and its spread in the 18th and 19th centuries. The starting point for such work is usually a study of the relevant original literature – Leibniz for example, as well as Condorcet, Poisson and Laplace. “But that’s just the beginning,” explains Daston. “You then have to put this literature in context. And that’s always the hardest part: Which context is relevant?”

To begin with, the young scholar studied probability theory from the perspective of its early applications. Some of these applications are still obvious to us today, such as games of chance, and insurance. However, she also came across a few real surprises, such as the probability of testimony. A witness in a trial asserts something;
how likely is he or she to be telling the truth? “It’s certainly an interesting question, but can it really be answered using probability theory?” wonders Daston.

That’s why it’s important to examine the intellectual context in which it was possible for leading mathematicians such as Leibniz, Laplace and Poisson to view questions of this type as a legitimate application of probability theory. The net is then widened to include the history of law, the long history of the arithmetic of proofs, the rules of circumstantial evidence and aleatory contracts. “As with all empirical research, the great thing is that you never know where it will lead. You come across so many wonderful surprises! The most difficult question is: When should you stop your research?”

Her research on the history of probability theory is what first brought Lorraine Daston to Germany after completing her doctorate. In addition to the two – positive – culture shocks she experienced in Bielefeld, there was another even stronger one: her meeting with Gerd Gigerenzer. As a scientist who had recently obtained his post-doctoral lecture qualification in mathematical models in psychology in Munich, he brought an extra dimension to the research group.

The two fell in love, and Bielefeld marked the start of a period of commuting, as Daston eventually returned to the US, this time to Princeton, while Gigerenzer stayed in Munich. The typical dual career problem: “It was very complicated. We commuted for a long time, until the birth of our daughter put an end to it,” explains Daston.

**NOT EVERYTHING WENT SMOOTHLY AT THE UNIVERSITY**

Consequently, she left the US in the early 1990s to take up a professorship at Göttingen University, which used funds from the Volkswagen Foundation to create a history of science chair. She remembers this period as an unhappy and frustrating one, mainly because nothing went right at the university in terms of organization and administration. Childcare was a particularly pressing problem. Finally, the whole family relocated to the Universi-
ty of Chicago, where Daston and Gigerenzer took up professorships.

Another turnaround came just two years later, in 1994. Daston was offered a professorship at Harvard University and Gigerenzer one at neighboring Boston University. At the same time, the Max Planck Society offered the two world-class scientists directorships in Germany: she in Berlin, at the newly established Max Planck Institute for the History of Science, and he in Munich at the Max Planck Institute for Psychological Research.

Initially, this meant another geographical separation, which neither of them was prepared to accept for long, and which ended only after Gigerenzer was appointed Director at the Max Planck Institute for Educational Research in Berlin in 1997. “If we hadn’t found a way to be together in one place again, we would have returned to Chicago,” says Daston.

In Berlin, the new institute started life under fairly bizarre circumstances on a historical site in Berlin. The new Max Planck Institute started life under fairly bizarre circumstances on a historical site in Berlin.

Republic had premises to rent. “The first time I came, Jürgen Renn was sitting there in a completely empty room, with a telephone on his lap. That was the institute.” In summer 1995, when she finally arrived in Berlin, Renn had gotten things up and running: “It was nothing short of heroic, the way he conjured the institute virtually out of nothing.”

Since 2007, the institute has been housed in its own new building in the quiet, leafy Dahlem district of Berlin, right next to the first Kaiser Wilhelm Institute. The library forms the heart of the three-story building. Wrapping all around the bottom floor of the institute, the bright and airy space is filled with light from a glassed-in inner courtyard. The Directors were involved in the planning, Lorraine Daston’s suggestion being that the library be open to institute scholars around the clock, as the 65,000 or so books form the basis of all of their work. Lorraine Daston occasionally sits here reading before 6 a.m. For her, working with books and other sources is still the most important part of her scientific activity. “If I no longer had time to go to the archives, I’d kill myself,” she laughs. She recently met a colleague in Paris who is on sabbatical and thus has a whole year to spend in the archives. “I was so envious! For me, it’s oxygen, pure and simple.”

DATA ARCHIVING AS THE BASIS OF SCIENCE

She herself spent three days searching the archives of the Académie des Sciences for unusual tabular presentations from the 17th century. A brief trip to the Royal Society of London Archives was next on the agenda for her current project on the history of the sciences of the archives, in this case meteorology.

The sciences of the archives depend crucially on the collection and storage of data. Some fields, such as astronomy and climate research, have objects of inquiry that span centuries or even millennia. They make use today of data that was collected in ancient times, and they are now collecting data for researchers who will need comparative data several hundred or thousand years hence. How was data sorted, classified,
and displayed – for example, via tables – contextualized? How should data be stored and presented so that it is still available to help future generations?

**CAN TRUTH HAVE A HISTORY?**

This is just one instance of how history of science is at the cutting edge of current research, and has a direct impact on it. It also plays a reflective role for today’s scientists. “The extreme dynamics of their science means that most scientists scarcely have the chance to think about two fundamental questions. First: Where do my research questions come from? Second: If everything we are publishing now will already be obsolete in ten years, why are we doing it? What does it mean to have a concept of truth that is time-dependent?” says Daston.

As an in-demand scholar, Lorraine Daston travels all over the world, and not only to present papers. Working with students is also one of her main interests. She therefore continues to commute to the US, where she teaches for several weeks a year at the University of Chicago. Much of her family still lives in the US. Nevertheless, she also feels very much at home in Berlin. “Because the city is such a magnet for young people, there’s always a hint of electricity in the air.”

Now that her daughter has left home, Daston’s full schedule once again allows for an occasional visit to the opera, to see Richard Strauss’s “Helena in Egypt,” for example, a performance by the Philharmonic, or to one of the many museums. The Max Planck Director also enjoys reading poetry. “I have eclectic tastes: all eras, in all the languages I understand. If I had time, I’d like to learn Polish. Even in translation, 20th century Polish poets are stunning – it’s hard to imagine what they would sound like in the original.”

She would also like to sing in a choir again, works by Bach, Bruckner, Ives, as she did during her student days. But basically, Daston admits she doesn’t need any unusual hobbies. “My vocation is so broad that I don’t need to look for diversions.” So broad that even a return to astronomy doesn’t appear to be ruled out. “And I still dream about taking up something completely new – Egyptology, perhaps, or crystallography.” As always, there are no limits to her curiosity.

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**GLOSSARY**

**Epistemology**

Epistemology (theory of knowledge) is a sub-field of philosophy concerned with the question of how belief is generated, what knowledge processes are conceivable, how justified belief is under different conditions, and how it is possible to tell that belief is based on knowledge.

**Probability theory**

Probability theory is a sub-field of mathematics based on the formalization of modeling techniques and the investigation of random events. Along with mathematical statistics, it constitutes stochastics. The key elements of probability theory are random events, random variables and stochastic processes.
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The Satellite with X-ray Vision

In the early hours of October 23, 2011, ROSAT was engulfed in the waves of the Indian Ocean. This was the end of a success story that is unparalleled in German space exploration research. The satellite, developed and built by a team led by Joachim Trümper from the Garching-based Max Planck Institute for Extraterrestrial Physics, not only found more than 150,000 new cosmic X-ray sources, it also revolutionized astronomy. TEXT HELMUT HORNUNG

The pile of debris came from the southwest, flew over the Gulf of Bengal and finally crashed into the sea at 450 km/h. There were no witnesses. Didn't the most famous German research satellite deserve a more fitting finale? At least the German weekly news magazine Der Spiegel took pity and tried to save what could be saved. In an article entitled "Directly in its Path" published on January 30, 2012, it reported that ROSAT fell to Earth "just barely missing the Chinese capital Beijing." The satellite "would likely have torn deep craters into the city." The magazine believes that the catastrophe could even have damaged German-Chinese relations. Joachim Trümper smiles broadly when confronted with this: "The likelihood of a single person being injured was roughly one in ten billion."

When you talk to Trümper about ROSAT, you can certainly detect a hint of wistfulness. "It was our baby," says the professor emeritus at the Max Planck Institute for Extraterrestrial Physics. The 78-year-old has dedicated more than half of his research life to the X-ray satellite. Joachim Trümper remembers the launch date on June 1, 1990 like it was yesterday, and was, of course, present at Cape Canaveral Space Center in the US. A few days before lift-off, he once again traveled in the elevator to the top of the Delta II launch system. "I took a final look at ROSAT through a window there," says the astronomer.

While Trümper was with some of his team members in the US, those who had remained at home witnessed the launch at the Oberpfaffenhofen-based research center. The control center at the German Aerospace Center (known by its German acronym DLR, Deutsches Zentrum für Luft- und Raumfahrt) is the Bavarian equivalent of America's Houston, and was involved in manned projects such as the two space shuttle missions D1 and D2 in the 1980s and 1990s. The experts were now expected to "fly" the two-and-a-half ton ROSAT, worth several hundred million Deutschmarks at the time, monitor its functionality, and constantly send commands and receive data via the DLR antenna in Lichtenau, near Weilheim, Germany.

Friday, June 1, 1990. In the evening, more than 500 guests have gathered at the German Space Operations Center in Oberpfaffenhofen. The live transmission from Cape Canaveral was broadcast on a large screen. Five minutes before the scheduled take-off, a civilian plane suddenly appeared above the campus; the countdown had to be interrupted. "That was the standard joke played by the launch team, to increase the tension," recalls Trümper. Ten minutes later, everything was back on track. In Oberpfaffenhofen, hostesses served champagne, and the guests counted down the last seconds. As the rocket took off into a perfect blue sky 8,000 kilometers away, everyone shouted 'Go, go, go!' and the Gilching brass band played march music.

Between the folklore in Upper Bavaria and the crash into the Indian Ocean lies not only a span of 21 years and 5 months, but also an exceptionally fruitful yield of scientific findings. X-ray astronomy is a very young discipline, as the Earth's atmosphere allows only a fraction of the radiation through from outer space, including visible light and radio radiation. However, in order to illuminate the universe with X-ray eyes, we have to leave the Earth's protective atmosphere behind us. American researchers thus discovered the Sun's X-ray radiation in 1948 using a seized V2 rocket. Today, the observatories are stationed on satellites.
Visible light can easily be focused using lenses or mirrors, but this can’t be done in the case of X-ray radiation. Because of their high energy levels, photons have a “penetrating” effect similar to that of bullets. For this reason, in the early 1950s, physicist Hans Wolter developed the principle of a special telescope in which parabolic and hyperbolic mirror segments focus the incidental X-ray light at a low angle. The plan was to deploy a Wolter telescope on ROSAT.

First, however, one or two obstacles had to be overcome. As early as 1972, Joachim Trümper resolved to begin developing the required instrument. Three years later, his group participated in a national invitation to tender in Germany for major scientific projects. Out of the large number of proposals submitted, three were chosen. ROSAT was among them.

In 1980, when the then German Federal Ministry of Research and Technology called for “substantial international involvement,” Trümper went looking for partners. “To avoid having the project mired in bureaucracy for years, we asked the Americans to look after the launch. And we asked the British to contribute to and operate a separate, smaller telescope for the extreme ultraviolet range.” The strategy panned out, benefiting the entire project.

In 1983, following years of studies, a number of companies (Dornier, MBB and Carl Zeiss) came on board. The engineers developed X-ray cameras and built a 130-meter-long test facility known as Panter. The telescope itself had an aperture of 83 centimeters and weighed roughly one ton. It consisted of four nested mirrors made from the heat-resistant glass ceramic Zerodur. Each of the gold-coated mirrors had a unique surface accuracy: compared to an area the size of Lake Constance, irregularities would be equivalent to a wave measuring roughly one hundredth of a millimeter. As a result, the telescope made it into the Guinness Book of Records for the smoothest surface.

Then came January 28, 1986. The Challenger space shuttle exploded into a ball of fire just 73 seconds after take-off. All seven astronauts died, and America’s manned space travel program went into hiatus for two and a half years. ROSAT was actually supposed to be sent into orbit in 1987 – on a space shuttle. This was no longer possible. “We now had to completely retrofit the satellite for launch with a rocket,” says Joachim Trümper.

This challenge was also met successfully. And, in the end, the technology and design were not the only record-breaking features. Even the first objective of the mission – charting the entire X-ray sky with an imaging telescope – exceeded all expectations. One of ROSAT’s predecessors was the Uhuru satellite, launched in December 1970. With its simple instruments – collimated proportional counters – it discovered 300 new celestial objects. A decade later, the Einstein observatory, with a Wolter telescope on board, increased this number to 5,000. And then ROSAT came on the scene: within the first six months alone, the scout found more than 100,000 new X-ray sources.

ROSAT subsequently observed selected sources: objects in the solar system, stars and gas in the Milky Way, distant galaxies. This second phase was supposed to last one year – which then turned into eight. The Max Planck researchers could always be counted on for a few surprises. Their satellite delivered the first X-ray image of the moon, and discovered the emissions from the Hyakutake comet. The latter was initially a puzzle, as comets were considered to be “dirty snowballs.” But to emit X-ray light, temperatures of millions of degrees are required, or very high-energy electrons. The solution: comets don’t generate radiation themselves, but are illuminated by their interaction with the solar wind, a stream of electrically charged particles.

ROSAT delivered the first complete overview of the universe, from the tiny brown dwarfs to the red supergiants, and observed compact stellar remnants such as white dwarfs, neutron stars, black holes and supernova remnants. Studies of galaxy groups and clusters provided new information about the role of dark matter in the evolution of the cosmos. Finally, ROSAT proved that active galactic nuclei and quasars on the edges of space and time contribute at least 80 percent to the background radiation in the X-ray range, thus solving a 30-year-old puzzle.

While the scout diligently collected data, its gyro, used to stabilize the satellite in space, began to fail. The researchers, especially Günther Hasinger, who would later become a Max Planck Director, and the MBB engineers, quickly adapted the navigation system and equipped ROSAT with a new, yet age-old system: it used compasses to orient itself with the Earth’s magnetic field. The satellite now worked perfectly again.

On April 25, 1998, however, the main star sensor on the X-ray telescope broke down. ROSAT had finally become too old. Despite the increasing obstacles, the observatory kept going until December 17, 1998. Contact was lost on February 12, 1999. ROSAT had done more than just fulfill its mission. A total of 4,000 scientists from 24 countries use its data. More than 4,000 articles in journals referred to the satellite, and the Max Planck Society issued its longest press release ever, at 36 pages.
Navigating by the Minerva Compass

Excellence and integrity – the principles underlying the MPS compliance system

Accordingly, Friese always attaches the Minerva pin to his lapel when giving lectures. “We can all identify with the logo. And identification is the source of integrity.” He has worked at the MPS since the beginning of 2011, observing time and again how employees live this mindset. “It’s part and parcel of the MPS’s excellent reputation,” says Friese. He sees his role as that of advisor to all employees, be they scientists, administrators or general management staff, and emphasizes “lived compliance” as a common duty. “This cements our excellent reputation, which is key in a scientific environment in terms of the MPS as an attractive employer, for example, as well as with respect to our financial backers.” He also points out that, if a legal violation occurs, it is not only the individual who is liable, but ultimately the MPS as a whole.

Friese, who comes from Plauen in Vogtland, is an enthusiastic mountain climber and lives just outside of Munich with his wife Anja and son Thorben. He studied for his first degree in public administration in Munich and, after obtaining a Master of Public Administration in Berlin, he worked for seven years at the German Patent and Trademark Office in Munich in a similar role to his current one. In addition to the training courses for which he travels all over Germany advising institute employees, he also devised a compliance system for the MPS, integrating all of the principles and organizational measures that ensure that processes are carried out by the book. The system is based on the Guidelines and Rules of the Max Planck Society on a Responsible Approach to Freedom of Research and Research Risks adopted by the Senate in 2010.

Friese has identified nearly two dozen “compliance areas” in all: from public procurement law, IT security and scientific misconduct to occupational health and safety and acceptance of gifts. He is able to clarify the legal position on every topic, supplemented by the MPS’s own additional criteria. These

Not just obeying the rules, but also thinking about one’s behavior as an individual – that’s the secret of a good corporate culture. The MPS aims to provide better guidance on this in the future.

He plugs in his earphones on his way from the airport to downtown Cologne. But on this particular Friday morning, Sven Friese, Officer for Compliance and Corruption Prevention at the MPS, is not listening to pop or classical music, even though he enjoys listening to Internet radio when he’s on the go. Today, Friese is tuned in to “higher things,” namely the livestream from Bellevue Palace. As he travels on the commuter railway, he’s listening to German President Christian Wulff accepting the consequences of his actions and announcing his resignation. “This was the logical outcome given the accusations against him – it was all about trust in the German legal system, especially the principle of equality,” says the 38-year-old.

Friese replied to these e-mails at length. At the end of the day, it’s all a question of proportion – and there’s a difference between a simple ballpoint pen and a hand-signed art calendar. The question of whether people should accept invitations and gifts is only a small part of his job. Compliance means more than this; the English word, which has recently also found its way into the German language, is about abiding by the law, and it defines the regulations that apply to all employees. These regulations are both external and internal, and company ethics also have a part to play. “As the patroness of science, Minerva embodies fundamental MPS values – excellence and, in terms of compliance, integrity above all.”

ADVISOR ON CONFLICTS OF INTEREST

Friese believes that these principles were shaken to the core by the scandal surrounding Wulff. “Around Christmas time, I received e-mails asking how it could be that MPS employees had to return gifts while the news was full of other people having entire holidays paid for.”
may involve the ombudsman procedure, in the case of scientific work, or, in the case of technology transfer, the clearing office, which assists with outsourcing. However, the quality of a compliance system is about more than just rules. “It’s important that people live the corporate values – and that employees live up to their responsibilities.”

This becomes easier when the complexity is manageable, namely when someone cuts through the thicket of rules. To this end, Friese and a working group are drawing up a draft code of conduct, to be agreed with the MPS governing bodies. “The code of conduct will serve as a common denominator, providing clear guidance to all employees, whether they are scientists or service personnel.”

Obviously, not all individual cases can be covered. “The code of conduct will thus provide further guidelines; procedural channels will have to be clarified, and contact persons designated.” And the advisory service will remain a key part of all of this. After all, balanced judgments are often necessary – black and white rules can’t always be applied to the everyday working world.

Take, for example, the following problem that Friese recently had to deal with at one institute: When a scientist applied for a visa for a research trip, an extra fee was suddenly brought into play. “Going along with this would be a clear case of bribing foreign officials,” says Friese. The general advice was thus: Don’t pay. “But if you’re stuck all on your own at a border checkpoint, and you absolutely have to get the stamp in order to proceed, you’d be forced to take a different approach.” Integrity, however, would demand that you report the incident to the institute, thus keeping your conscience clear.

QUESTIONS FOR THE INNER COMPASS

- Am I acting lawfully? Is my conduct ethically reasonable?
- Am I acting solely in the interests of the MPS?
- Am I prepared to take responsibility for my actions?
- What public impact will my conduct have?

To avoid conflicts of interest, it is useful to be aware of these questions – and it is important to be able to answer them with the company in mind. If conflicts of interest arise, the superior is the first point of contact, followed by the Compliance Officer, who is bound by confidentiality.

Telephone: 089-2108-1888, e-mail: compliance@gv.mpg.de
Intranet: https://intranet.mpg.de/beauftragte/compliance

Debate 2.0 – How the Science Gallery Talks in Berlin Work

When a Science Gallery Talk is held in Berlin, it isn’t at all like a traditional podium discussion. With this format, the audience is directly involved, as was the case, for example, with the event entitled “Are we all becoming cyborgs – how far does technology penetrate into our brains?” Not only can audience members ask questions, they can also use their mobile phones to send text messages, which then appear directly on the screen. The podium guests, Moritz Grosse-Wentrup, an engineer and brain researcher from the MPI for Intelligent Systems, and Jens Clausen, philosopher and biologist at the University of Tübingen’s Institute of Ethics and History of Medicine, responded to the questions directly. However, the audience has even more influence on the direction taken by the debate: participants can use laser pointers to decide which topics will be discussed. Several options are presented for selection on the screen, sometimes accompanied by short video clips. The debate continues on the topics at which the most light-points accumulate. The format has proven to be a big hit with audiences. The hall at the Berlin-Brandenburg Academy of Sciences and Humanities, which organizes the series jointly with the Science Gallery team, is always full.
Switching Seats for Future Prospects

Speed Informing brings doctoral students and alumni together and reveals the variety of careers open to MPI alumni.

The series of events is a little like speed dating – but professional careers, rather than flirting, is on the agenda. In the process, doctoral students get to know alumni in ten-minute sessions. Six MPIs have already taken part.

The lecture hall at the MPI for Molecular Genetics in Berlin is perfectly set up for a career information event. But now the chairs have to be removed to make sure there’s enough room – for cardboard stools. These are arranged in circles on the blue carpet for five small groups who are going to get to know one another. Just like speed dating, except that the purpose of the event is not to start an affair or find the love of one’s life, but to sound out career prospects. It is an initiative for MPI doctoral students who have registered especially for the occasion – and who will not only have fun, but will also come away with some tips for the future.

The 30 participants don’t know much, only that they are at a Speed Informing function, a new event format with the theme: “Paths to professional life – what happens after Max Planck?” During the event, doctoral students meet up with alumni of the Max Planck Society. At this particular event, the alumni are mainly those who have chosen a career outside of science following their doctoral studies.

The event starts with the necessary facts and figures. Kolja Briedis, Project Manager for Graduate Research at the Hanover-based HIS-Institut für Hochschulforschung (an institution that conducts research on higher education) has come to Berlin. His key message is that it pays to have a doctoral – and not only because the unemployment rate among graduates with science doctorates is less than three percent. Earning potential and job satisfaction are also very high. Where do graduates go once they have completed their doctorate? The answer is quite surprising: 42 percent of all doctoral graduates remain at the university, at a non-university institution or at another institution where the focus is predominantly on research and teaching. The remaining 58 percent of doctoral graduates move into areas that have no research connection.

**IT PAYS TO HAVE A PH.D.**

This multifaceted career path is also reflected in the selection of alumni present today: a patent attorney, two self-employed graduates, a CEO of an integrated research and treatment center at a university hospital, and a head of marketing and medicine in a pharmaceutical company.

This is where the cardboard stools come in. Each alumnus or alumna joins one of the circles and the event begins: a maximum of six doctoral students can question a former student in each session. A piercing whistle marks the beginning of the Speed Informing discussions. Each group has ten minutes before it is startled again by a piercing whistle. The doctoral students then rotate to the next circle. The 30 young junior scientists are highly focused as they listen intently to their predecessors, asking specific questions and occasionally making notes to record the details.

**ENOUGH TIME TO ASK IMPORTANT QUESTIONS**

The discussions continue at the next get-together. “I tried to reassure the young people that they can confidently apply for jobs with their heads held high because they have completed their doctorates at a Max Planck institute,” says Wolfgang Kapfer, former doctoral student and now head of marketing at Sanofi-Aventis. “This is an important calling card to have, especially right at the start.” He likes the fact that the press office at Administrative Headquarters, together with the press officers of the relevant institutes, initiated the series of events. Other alumni report that they would have liked to participate in similar initiatives when they were completing their doctorates.

A total of six institutes participated in the first Speed Informing series. “The collective enthusiasm for this new format was clear.” says Christina Beck, Head of Press and Public Relations at Administrative Headquarters. According to the students, they found it considerably more informative to be able to speak to all the alumni for ten minutes instead of sitting through various talks, as is usual at career events. “I could ask questions that were important to me, and I gained some insight into the world outside of science.”

Further events are planned – including events involving alumni who have continued their careers in science. This suggestion also came from the feedback sheets. The general consensus is that the right priorities were addressed. After all, as one doctoral student wrote, “it is much easier to get to know heads of a junior research group than to build contacts with people outside of science.”
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