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Dear Readers,

We are currently confronted with a seemingly insoluble dilemma: According to the International Energy Agency (IEA), global demand for energy will increase by around 50 percent by the year 2030. Yet during the same period, carbon dioxide emissions worldwide must be cut in half if we are to limit global warming to around 2 degrees Celsius by the end of the century. Such is the summary of current forecasts in the eyes of the German Advisory Council on Global Change. There is only one way out of this precarious situation: through intensive research into entirely new technical approaches to energy generation and conversion. It is not enough to tinker with our current energy mix in order to bring us much closer to the goal of sustainable energy supply. What we need, instead, are innovations of the kind that only basic research can provide.

Max Planck scientists are thus working to develop new materials for solar cells and fuel cells; they are attempting to reproduce the solar furnace here on Earth, and to extract energy from plant waste; they are exploring ways to store hydrogen more safely and more compactly; and they are laying the foundations on which to make batteries so efficient that they can also power vehicles.

As the former chief economist of the World Bank, Nicholas Stern, writes in his book *The Global Deal*, new technologies and investment opportunities in low-carbon-dioxide and renewable energies will, in the coming decades, become the principal drivers of sustainable economic growth. They also offer the only chance to slow down the global rise in temperatures associated with climate change. Stern therefore calls for more public-sector support for technology and research: “It is of the utmost importance,” Stern writes, “that research institutions throughout the world receive the support they need to impartially develop new ideas.”

If new results are to contribute as rapidly as possible to resolving the energy issue, basic research should ideally be working hand in hand with applied research. This is precisely the function of many joint projects shared between Max Planck and Fraunhofer Institutes, two of which we present in this issue: In the ProBio project, scientists at the Max Planck Institute for the Dynamics of Complex Technical Systems are working together with colleagues at the Fraunhofer Institutes for Factory Operation and Automation and Ceramic Technologies and Systems to develop a new generation of fuel cells that are powered ultimately by biomass. Furthermore, chemists at the Max Planck Institute for Solid State Research are cooperating with the Fraunhofer Institute for Silicate Research in order to draw out particularly heat-resistant ceramics to create new types of fibers for composite materials.

However, these fundamental technical challenges are not the only issues that climate change and future energy supply pose for us. The human sciences, too, are confronted with new questions. Researchers at the Max Planck Institute for Comparative Public Law and International Law are studying the legal implications of geoengineering: How can large-scale interventions aimed at restricting climate change be compatible with international law if there is a risk that they may have undesired side effects? The articles in this issue of *MaxPlanckResearch* alone show the scale of the tasks the world, and scientific research in particular, is facing in the short and medium term. They also clearly demonstrate that the Max Planck Society is making a major contribution toward meeting these challenges.

Peter Gruss,
President of the Max Planck Society
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**Heli-trainer Sets New Standards in Pilot Training**

Heli Aviation GmbH, KUKA Roboter GmbH and the Max Planck Institute for Biological Cybernetics joined forces at this year’s ILA, the leading international trade fair for the aviation industry, to present a joint concept for a new type of helicopter flight trainer.

The goal of this joint development project is to create a realistic system that makes it possible to train pilots safely, effectively and economically. Unlike normal flying lessons, critical maneuvers can be repeated often and simulated to the point of crashing – without the attendant consequences. In practical training, instructors are compelled to intervene immediately when their pupils make an error. With the aid of the Heli-trainer, it doesn’t take long for would-be pilots to develop a feel for the required movements and gain a better understanding of the consequences of pilot error, as well as learning to maneuver in a safe environment with a steep learning curve.

One of the biggest technical challenges in developing such a trainer is the need to replicate the movements of complex real-life systems in a minimum of space in such a way that the pilot actually has the feeling of flying a real aircraft. The KUKA model KR 500 TÜV robot, modified by the Max Planck Institute for Biological Cybernetics to be a motion simulator, is a heavy-duty robot with an attached helicopter cell in which one or two persons can practice realistic helicopter maneuvers.

**Paradigm Shift in Tumor Treatment**

Individual tumors differ substantially in their mutation profiles, even when they are produced by the same type of cancer. That’s why, in 2008, the International Cancer Genome Consortium (ICGC) was formed to create a comprehensive catalog of the genetic changes in tumors.

The organization currently encompasses 22 countries worldwide. Their goal is to provide predictive molecular markers for every individual type of tumor and every patient. This will enable doctors to avoid ineffective treatments and decide on the most appropriate, risk-aware therapy in every case, as well as supporting the search for new forms of treatment. At the beginning of 2010, German scientists, including the group headed by Hans Lehrach at the Max Planck Institute for Molecular Genetics in Berlin, initiated the joint Pediatric Brain Tumors project, which is coordinated by the German Cancer Research Center in Heidelberg. Brain tumors, which are diagnosed more than 300 times a year in Germany, are the main cause of cancer mortality in childhood. The German Federal Ministry for Education and Research and the aid organization Deutsche Krebshilfe e. V. are contributing 15 million euros over a 5-year period to support Germany’s participation in the ICGC.
“The goal is to create a designer microbe”

In May 2010, Craig Venter announced the creation of the first “synthetic cell.” His team succeeded in reconstructing the genome of the bacteria Mycoplasma mycoides piece by piece in the laboratory and transplanting it into the cell of another type of bacteria. In an interview, Ralph Bock of the Max Planck Institute for Molecular Plant Physiology gave us his thoughts on the results.

What is so special about Venter’s current work? Scientists have been transplanting genetic material from one cell to another for years in cloning experiments.

Ralph Bock: That’s right. But in cloning, the whole cell nucleus is transplanted into an egg cell from which the original nucleus was removed. So it is not just genes that are transferred, but proteins and enzymes as well. Venter has shown that transplanted DNA on its own can reprogram a cell. But what is really new is that, for the first time, the genes of a living organism have been manufactured entirely in the laboratory. To achieve this, the genetic sequence must first be precisely decoded and the DNA strand then assembled piece by piece. That is a huge achievement when you consider that the genome of this bacterium consists of more than a million components. One wrong component can result in the incorrect reading of a vital gene, meaning that the whole genome will fail. That’s what happened in this current work: the team spent three months looking for one missing base pair – one in a million!

What significance do these results have for research?

Ralph Bock: From a scientific point of view, the results were to be expected. Few scientists ever doubted that a correctly synthesized genome would work if it were introduced into a new cell. But it hadn’t ever been demonstrated experimentally. What’s more important is that, with the methods Venter’s team developed, we will soon be able to study genes more rapidly and on a larger scale, and modify them more efficiently than in the past.

Venter’s experiments are being described as synthetic biology. What are they intended to discover?

Ralph Bock: The goal is to modify genetic material in such away that its host acquires the desired capabilities. For instance, bacteria that produce active ingredients for drugs in large quantities – so a kind of designer microbe. In the same way, we could also create a minimized version of the genome. We still don’t know which genes an organism absolutely must have in order to live, and which ones it can live without. We still need to learn a lot more about how genes are regulated and how they influence one another – an important aspect of another modern area of the biosciences known as systems biology.

Are Venter’s results transferable to other organisms? Is it conceivable that human DNA could be manufactured in the laboratory and transplanted into a cell?

Ralph Bock: Not in the foreseeable future. One problem is the size of the genome: it wasn’t by chance that Venter picked a bacterium that has one of the smallest known genomes in the living world. By comparison, human DNA consists of 3,000 times more components. Decoding and re-synthesizing genomes of that order is not yet technically possible. Moreover, the “design plan” of animals and plants is not limited to just the sequence of DNA building blocks. Both these building blocks themselves and the proteins that surround the DNA can be chemically altered and regulated. In bacteria, such epigenetic changes are of little importance. Synthetic plant or animal cells, however, would have to contain all of the epigenetic changes at the correct points – and we are decades away from doing that.

Nevertheless, critics are accusing Venter of playing God and creating artificial life.

Ralph Bock: That’s an exaggeration. Venter and his colleagues have synthesized genetic material, but they implanted it in a natural bacteria cell. So ultimately, only a tiny, albeit central, part of the new cell originated in the laboratory. To qualify as artificial life, the whole hardware of the cell would have to be made in the laboratory, its protein and energy factories, or maybe the membranes with all their transport systems for absorption and secretion. We are talking here of tens of thousands of components that would have to be synthesized and correctly positioned to make a completely artificial cell.

Is that even conceivable?

Ralph Bock: It is certainly conceivable, but very, very difficult, of course. Fats, sugars and amino acids could still be manufactured relatively simply, but synthesizing larger proteins is much harder work. At present, large macromolecular complexes can’t be manufactured at all by purely chemical means. In my opinion, in this respect, too, we are still decades away from creating a completely artificial cell.

One of the accusations concerns the patents that Venter filed for his discoveries. Could these hinder further research?

Ralph Bock: Such patents generally come into play only when third parties want to use the new technology commercially. They have no substantial impact on basic research.

What ethical questions do the results raise?

Ralph Bock: At the present time, in my opinion, none, because the boundaries between traditional genetic engineering and synthetic biology are fluid anyway. We have been adding new genes to the genetic make-up of cells or disabling existing ones for more than 20 years. Even the use of chemically synthesized genes has been part of the standard genetic engineering repertoire for years. Many of the pharmaceutical drugs used today are already produced by such genetically modified microorganisms. Venter has now broadened the field of possibilities with which we may soon analyze and specifically modify the building plan of life – nothing less, but nothing more either.
Few, if any, areas of research have developed as dynamically in recent years as iPS technology. With the aid of simple tricks, researchers can restore mature body cells to a pluripotent state in which – like embryonic stem cells – they can once again form all of the more than 200 cell types that make up the body. The method by which these so-called induced pluripotent stem cells (iPS cells) are manufactured has been considerably simplified since it was first established in 2006. The Max Planck Institute for Molecular Biomedicine in Münster has made a substantial contribution to these advances and now intends, in cooperation with the new reference center, to devote its attention specifically to developing and refining iPS technology. The reference center provides a basis for strategic cooperation, as well as a methodological platform for the ongoing development and marketing of iPS cell technology itself and the resulting products. Of the 80 million euros in start-up funding, 75 percent will be provided by the state of North Rhine-Westphalia, with the Federal Ministry of Education and Research (BMBF) contributing the remaining 25 percent.

MaxPlanckResearch Prize Awarded

The MaxPlanckResearch Prize, endowed with 750,000 euros, has been awarded to Timothy George Bromage of the New York University College of Dentistry and Michael Tomasello of the Max Planck Institute for Evolutionary Anthropology in Leipzig. “The Alexander von Humboldt Foundation and the Max Planck Society wish to recognize two scientists who have made a significant contribution to improving our understanding of the evolution of mankind,” said Max Planck Society President Peter Gruss at the award ceremony. Michael Tomasello is studying the origins of language and the cultural evolution of humans. In empirical studies of small children and primates, he is researching the cognitive abilities that distinguish man from other highly developed primates. Timothy Bromage is investigating what can be learned about the living conditions of early man from the structure of bones and teeth. Among other findings, he has discovered how to decipher the speed of growth and individual life histories of early humans from the structure of their bones. The MaxPlanckResearch Prize is funded by the German Ministry of Education and Research. Secretary of State Cornelia Quennet-Thielen presented the awards at an event hosted by TV journalist Kristina zur Mühlen at the Hanover Congress Center. The prize is given each year to two scientists of international renown – one working in Germany and one working abroad – and is intended to enable them to pursue their work through the medium of international cooperation.

Two Max Planck Centers Planned for South Korea

Max Planck Society scientists are expanding their cooperation with South Korean colleagues at the private Pohang University of Science and Technology (POSTECH). Max Planck President Peter Gruss and the President of POSTECH, Sunggi Baik, signed an agreement in Munich on June 14 for a research initiative that will initially lead to the establishment of two international Max Planck Centers in the fields of attosecond science and complex phase materials. Scientists from both institutions are already working together in these fields. The new centers will allow them to accelerate the interchange of expertise and personnel, and support the joint training of junior researchers.
“Jugend forscht” – National Awards Presented

The winners of the 45th national “Jugend forscht” competition recently received their awards in Essen. Ferdi Schüth, Director at the Max Planck Institute for Coal Research in Mülheim, congratulated the winning trio in the biology category: Florian Schreier, Thomas Irion and Lukas Dieterle impressed the jury with their work on the schooling behavior of fish. At the invitation of the EU, they will now travel to the 22nd European Union Contest for Young Scientists in Lisbon. The three budding researchers from Baden-Württemberg analyzed the schooling behavior of various species of fish before developing a simulation program with a virtual school of fish whose behavior corresponds closely with that of their real-life counterparts.

Meet Us On Facebook

For a little while now the Max Planck Society has had its own page on Facebook. With more than 400 million active users, around half of whom visit the site daily, Facebook is the leader among social networks. The users who meet here are mainly young people who are keen to share their experiences – for example about studying abroad and the trendiest places in town. We want to explore the potential of such community platforms as a venue for corporate communication. Right now, the number of users in direct contact with the Max Planck Society is still modest – our page currently has around 900 followers. The more the merrier!

On the Net

Cell Rejuvenation
At the Max Planck Institute for Molecular Biomedicine in Münster, Hans Schöler succeeded in turning back the clock just by adding a single factor, oct4, to neuronal adult stem cells: they develop into pluripotent cells, the all-rounders on which the hopes for regenerative medicine rest. To watch a German-language animated film showing how pluripotent stem cells can become a source of natural replacement tissue, offering a possible treatment for diseases such as Parkinson’s, visit: http://www.filme.mpg.de

Completely Complex
Sabine Sütterlin is a freelance science journalist. Since June of this year she has been reporting on her “field studies at the three Max Planck institutes in Dresden, where researchers are exploring complex systems and molecular processes in cells and solids.” In her blog entitled “Completely Complex” (in German), she displays a sense of humor and a gift for observation as she describes such topics as chaperones that whip proteins into shape and fruit fly embryos that turn into movie stars: http://www.scienceblogs.de/komplett-komplex/

On the Fascination of Black Holes
In her day job, Annalie is a musician. However, she is also the daughter of Bernard Schutz, Director at the Max Planck Institute for Gravitational Physics in Golm. That is why Annalie now finds herself interviewing leading astronomers and asking, in a refreshingly natural way, what it is that fascinates them about black holes. The resulting 15 videos prefaced by a snappy trailer are aimed at a younger audience. A further 10 episodes about gravitational waves are set to follow: http://www.scienceface.org/
The State’s Tax Predicament

It is a subject guaranteed to cause a stir: the practice by which international groups use the domestic infrastructure to generate profits that are then channeled abroad as interest payments that bypass the German tax authorities. Preventing the practice, however, is difficult, and not just from a legal perspective: economically, too, an ill-considered tax impost can do the government more harm than good.

TEXT CHRISTIAN MARQUART

German tax law is littered with opportunities for companies to legally avoid paying taxes. A prime example in the public discourse is the case of the German subsidiary of a major Swedish furniture retailer. In 2003, this subsidiary generated profits of more than 300 million euros before license fees and interest payments – but its tax burden in Germany was a mere 50 million euros. The company succeeded in transferring a large share of its profits abroad, where its earnings were subject to a substantially lower tax rate. The group was able to drastically reduce its tax burden, to the detriment of the German treasury. It is not surprising that politicians would like to prevent such legal “tax dodges.”

Companies are able to save taxes not least because they can meet their financial needs for raw materials, machinery, buildings, wages and other production costs in two ways: through equity or through debt. Equity can be acquired, for example, by issuing (new) shares in the company. A capital investor who buys the shares provides the company with funds for an indefinite period and, in return, acquires a stake in the opportunities and risks of the undertaking. In good times, he makes a profit, and in bad times, he suffers losses.

In the case of debt, in contrast, the simplest alternative is a straightforward loan – money on which the company must pay interest, even in years in which it realizes a loss, and which must be repaid within a contractually fixed period. It is not until equity has been consumed that losses must be covered through debt. In that case, creditors may have to defer repayment of the loan, or in the event of insolvency, forfeit some – in the worst case even all – of the expected repayment.

In general, national law places few stipulations on how the owners of a business may fund their undertakings. As long as they are not bound to consider any legal requirements, companies follow economic criteria.

One factor that is of critical importance, particularly to multinational entities, is the difference in the tax treatment of equity and debt in different...
countries. When a corporation that is resident in Germany raises equity, it has to pay full tax on the entire return on capital. While it is true that investors, too, must generally pay tax on the return on their investment when profits are distributed, the bulk of the tax burden is borne by the company.

The picture is quite different when the company chooses to meet its financial needs with debt, such as loans. In this case, the company pays tax only on that portion of the return that is not paid to the lender as interest. The reason is simple: the interest payments are deductible from the tax base – that is, the income on which the tax liability is assessed. The lender, however, must pay full tax on the interest received.

Even if the state treats equity and debt differently for tax purposes, the fiscal revenue is still the same provided that, at the end of the day, both alternatives bear the same total tax burden. However, the levies on these two forms of financing vary from country to country. This is where the opportunity for multinational enterprises to reduce their overall tax liability arises. There may, for example, be a tax advantage for a parent company resident in a low-tax country to pass on its equity in the form of a loan to a subsidiary that is resident in a high-tax jurisdiction.

The problem for the tax authorities is obvious: excessive borrowing by a subsidiary from abroad erodes the domestic tax base. Germany traditionally ranks among the high-tax countries. Multinational enterprises based in Germany thus have an incentive to transfer domestic profits to foreign subsidiaries in the form of interest payments. Ideally, the foreign group member recipient will pay substantially lower taxes on the interest received. This issue is of critical importance, because a country loses its tax jurisdiction once profits have been transferred abroad.

Of course a high-tax country such as Germany has a legitimate interest in preventing companies from offsetting the interest they pay against their domestic taxable base and transferring net profits abroad. After all, the government provides the infrastructure that these companies need and thus contributes significantly to their success. If the tax base shrinks, the government has no incentive – and moreover no funds – to maintain or even expand this infrastructure.

But how can governments prevent companies from transferring profits abroad as interest payments? First of all, one might consider changing the rules and, in the future, providing for equal tax treatment of equity and debt. Companies would then be unable to deduct interest payments on debt – just as they cannot deduct dividends on equity – from their taxable profits. However, this would overturn fundamental principles of the current tax system. More importantly, unless such a change is harmonized internationally, it would result in a dramatic location disadvantage, as companies that are resident in Germany would face substantially higher costs. Thus, at least for now, a reform of this nature is not a viable solution.

Another approach might be a withholding tax regime that applies to interest payments made to foreign recipients. In this case, the resident company still pays the tax, but only as an agent, and it is actually the foreign recipient that is liable for tax to the German tax authorities. This work in exactly the same way as the withholding tax that banks remit to the treasury on behalf of their customers (Abgeltungsteuer). However, German legislators have deprived themselves of this option by entering into double taxation agreements, not to mention a European Directive adopted in 2003.

This is why, in the end, there appears to be only one solution: in cases that the state perceives as abusive, it must restrict the deductibility of interest payments. Then excessive borrowing to the point considered to be abusive would be significantly less attractive. But there is more to developing a mechanism to expediently restrict the tax deductibility of interest than commonly meets the eye. This is mainly due to the constitutional constraints, policy con-

German subsidiaries benefit from moving a lot of profit abroad
considerations and economic criteria that legislators must take into account when drafting new rules on the deductibility of interest payments.

For example, research in the field of business administration and economics has not yielded any generally applicable formula for the ideal ratio of debt to equity. In fact, there are various factors that companies must take into account when deciding on their preferred method of financing in each individual case. Tax criteria are hardly ever the sole crucial factor. A company may, for example, be debarred from financing itself through an increase in capital (for instance by issuing new shares) because the corresponding resolution fails to find favor with the majority of existing shareholders. In this case, borrowing is the only option.

With only these considerations in mind, it is scarcely possible to determine unequivocally and feasibly whether a company is financed solely on the basis of tax criteria. Plus, already understaffed fiscal authorities can hardly audit a company’s financing relationships in every single case. If legislators want to get their hands on interest flowing abroad, they must ultimately find a blanket method by which to suppress excessive deduction of interest in association with cross-border lending arrangements.

On the other hand, the fundamental freedoms of the European Union, such as the freedom of establishment and the free movement of capital, demand equal treatment of internal and cross-border interest payments. Companies must therefore be able to offset these payments in equal measure against tax – irrespective of whether the interest is paid in Germany or sent abroad. So far, the Court of Justice of the European Union has allowed an exception to this strict policy of non-discrimination only where, taking into account all relevant circumstances, an administrative authority can prove that a specific financing arrangement is dictated solely by tax motives. For the reasons stated above, it appears to be virtually impossible to prove such a case, both in theory and in practice.

Thus, in effect, legislators are compelled to limit the deduction of interest also on purely domestic financing arrangements if the relevant conditions are met. By imposing sanctions on companies that operate and raise loans only within the borders of a country, legislators are inevitably exceeding their desired aim, as in those cases there is no risk that a portion of the tax base will be transferred abroad. Nevertheless, borrowing is impaired, with the result that even economically expedient loans – for example in connection with restructuring – may be beyond a company’s reach. In the worst case, the company thus affected is left with insolvency as its only option.

Such a situation is critical not only from an economic perspective, but in Germany, it also raises the specter of conflict under constitutional law. Permitting a company to deduct its interest expenses only under certain circumstances is limited by constitutional constraints. Under the tax system as it currently applies, interest expenses must be tax deductible as a matter of principle. Legislators are bound by this constitutional framework and cannot deviate from it at will. Specific justification is required.

The German Federal Constitutional Court is less strict on this point than the Court of Justice of the European Union, permitting blanket regulations.

Nonetheless, legislators bear the burden of proof to show that the formula limiting the deduction of interest targets, in the majority of cases, arrangements that are tax-driven. However, particularly in domestic cases, lawmakers will scarcely be able to prove their point: in such cases, tax aspects play at most a subordinate role, since the various forms of financing are generally subject to a more or less equal tax burden. Consequently, such regulations are at risk of being declared unconstitutional – especially when the unrestricted deduction of interest effectively becomes the exception rather than the rule.
Tax authorities that aim to restrict the deduction of interest find themselves between Scylla and Charybdis. Despite this, German legislators remain undeterred: to protect the tax base, a so-called interest barrier rule was introduced as part of the corporate tax reform of 2008. This represents a distinct tightening of the previous regulations, particularly insofar as it restricts the deduction of interest even on normal bank loans.

The interest cap is dependent on a company’s gross annual profits – that is, the earnings before interest, taxes, depreciation and amortization of the company’s assets. The higher the gross annual profit, the more interest a company may deduct from its taxable base. There is no restriction on the deduction of interest as long as a company’s interest expenditure equals or exceeds its interest income. As a result, banks, in particular, are effectively exempted from the restrictions on deduction: the law neither desires nor intends to impair their ability to borrow and re-lend. Interest may also be deducted in full provided that it does not exceed a certain amount, that the company in question is not part of a group, or that the German members of a group are not financed with debt to a proportionately higher degree than the group as a whole.

For legislators, the main object of the interest cap is to ensure that international groups distribute their financing costs equitably across the group and do not claim interest deductions in Germany alone. It also creates an incentive for multinational enterprises to transfer profits into Germany, since they can then offset a greater amount of their interest payments. However, this regulation hits German companies particularly hard when, in a crisis, their annual gross profits collapse. A mechanism was thus introduced recently that provides for the “smoothing” of gross profits over several years.

Despite its considerable complexity, the interest cap is not suited to identifying even roughly those financing arrangements that are motivated by tax reasons. The ratio between gross annual profits and interest costs gives no indication of whether or to what extent a company’s debt financing is driven by tax considerations. Highly profitable companies can still lend substantial amounts of capital, while companies with already weak earnings may, under certain circumstances, suffer a tax penalty despite being adequately financed with equity. The fundamentally convincing approach of comparing equity ratios fails in practice simply because a German company may not be able to provide evidence of the financing structure of its entire, often globally distributed group to a degree that satisfies the high standards demanded by the tax authorities.

In view of this unsatisfactory outcome, the question arises whether other jurisdictions have found more convincing solutions to the problem. Some countries use a company’s ratio of debt to equity to regulate the deduction of interest (as Germany did prior to the introduction of the interest cap). They presume that there is a common ratio of equity to debt. Another approach is based on a company’s assets: the higher the cumulative value of its assets, the more interest it may deduct. In practice, however, these approaches, too, yield arbitrary results. The “right” ratio of debt to equity does not exist – average equity ratios vary, in some cases widely, from one industry to another – and there can even be variations within industries. Nor is it possible, on the basis of the value of assets, to determine unambiguously whether a company’s borrowings are primarily tax-driven or are accounted for by other reasons.

All approaches thus far put into practice have proven unsuitable to even roughly identify those financing arrangements that are motivated by tax. And this deficiency can’t even be genuinely overcome by combining the various methods. Decisions on how companies finance themselves are simply...
far too complex to be convincingly modeled in a regulatory instrument that is workable in practice.

Place a blanket restriction on the ability of companies to offset interest, and the resulting legislation will always impact a considerable number of businesses that are not, or not primarily, financed through debt simply for tax reasons. Legislators who follow this approach to assert their justified interest in taxing domestic profits inevitably face comparison with the proverbial bull in a china shop.

All the more reason for them to have a clearer understanding that restricting the tax deductibility of interest is a politico-economic decision. It is a question not just of safeguarding tax income, but of the attraction of Germany as a place to do business. By structuring their finances in a specific way, companies may indeed succeed in spiriting their profits away right under the nose of the German taxman, and yet the effective reduction in their tax burden can be beneficial for Germany itself. The opportunity to save tax is, after all, a powerful incentive to invest here.

A country's attraction as a place to do business is dependent not only on its nominal tax rates, but on how investments are taxed generally. When interest can no longer be deducted from earnings as an operating expense, the effective tax burden increases. The more indiscriminately legislators limit the deduction of interest in their desire to protect the tax base, the greater the collateral damage to the economy and the greater the risk that the German Federal Constitutional Court will intervene.

Taking into account all of the above factors, the most viable option appears to be to make the deduction of interest dependent on whether the debt is invested in productive assets – for instance, plant and equipment, inventories or real estate. Besides the taxable income to be expected on such investments, in this case, there are additional positive effects on the labor market. It is also not unlikely that the stringent implementation of such a regulation would pass muster even in the eyes of the Federal Constitutional Court. With this in mind, it might be desirable for German legislators to reconsider their current concept for the restricted deduction of interest.

It is a question of both safeguarding tax income and Germany's future as a business location.

THE AUTHOR
Christian Marquart, born in 1983, has been working at the Max Planck Institute for Intellectual Property, Competition and Tax Law in Munich since the beginning of 2009. As part of his doctoral studies with Director Wolfgang Schön, Vice President of the Max Planck Society, he is conducting research on the issue of the transfer of profits resulting from the capital structure of business entities.
Stable, even when it gets hot: The ceramic fibers made from silicon, boron, nitrogen and carbon can withstand temperatures of more than 1,500 degrees Celsius.
A Material
That Keeps Its Cool When Hot

A great deal of energy could be saved if turbines and combustion engines operated at higher temperatures than they currently do. Ceramic high-temperature materials make this possible. Martin Jansen, Director at the Max Planck Institute for Solid State Research in Stuttgart, has been conducting research into just such a new material for 20 years. It is now ready for the market.

TEXT ROLAND WENGENMAYR

Anyone who discusses high-temperature materials with Martin Jansen quickly sorts our world into an imaginary temperature scale. We live at the very bottom, on a small, cool island where solid matter is possible. Above 4,000 degrees Celsius or so, all the solid materials with which we are familiar melt or decompose. When viewed on a cosmic scale, this is not particularly hot – temperatures of 15 million degrees Celsius, for instance, prevail in the center of our Sun.

Jansen presents a diagram that can be read as a kind of treasure map in the search for high-temperature materials. At the top of the hot hit-list is an alloy of tantalum, zirconium and carbon with a decomposition temperature of just under 4,000 degrees Celsius. Carbon follows in second place, at around 3,800 degrees – but not in air, as the oxygen would have caused it to burn up before then. “The sequence of these materials has been the same for 50 years,” explains the chemist, since science has not found a more heat-resistant material during this time. Obviously, even the strongest chemical bonds can hold atoms together as solid matter only at up to around 4,000 degrees Celsius.

HEAT-RESISTANT MATERIAL HELPS TO SAVE ENERGY

But Jansen’s research field lies between 1,000 and 2,000 degrees Celsius. His team in Stuttgart and his cooperation partners are developing new high-temperature materials that can be used in engines and turbines. The winners on the thermal hit-list are, unfortunately, not suitable for this, because materials for such applications must not only withstand high temperatures in the presence of oxygen, they must also cope with strong mechanical loads. In the large steam turbines that generate electrical energy in power plants, for example, the extreme tips of the longest turbine blades rotate at supersonic speed – subjecting them to enormous centrifugal forces.

Thus far, metallic materials have complied best with this spectrum of specifications. But even the most thermally stable alloys “scale” in air and soften above 1,000 degrees Celsius. Although modern aircraft engines and gas turbines in power plants operate at combustion temperatures of up to 1,400 degrees Celsius, a cooling stream of air must protect the metal components from the hot gas. This costs energy and decreases the efficiency of the turbines.

Jansen wants to increase the efficiency of heat engines, including turbines and all combustion engines. According to the laws of physics, their efficiency increases with the operating temperature. This is no less true for the engine of a motor vehicle than for the turbine generator of a power plant. Higher efficiency saves valuable fossil fuel and reduces the emission of climate-damaging carbon dioxide. In addition, combustion chambers that are not cooled reduce the emission of harmful nitrogen oxides.

Heat engines literally drive our society. Given their relevance, it becomes clear why Martin Jansen has been doggedly working on new high-temperature materials for more than 20 years. It is only one of his research
fields, of course, but it is obviously close to his heart. The answer to the question as to which materials could adequately replace the metals that have thus far dominated things was obvious to the inorganic chemist way back in the 1980s: only ceramics could provide a solution.

The ceramic high-tech materials that the Stuttgart chemists have been developing ever since, however, have nothing in common with conventional porcelain. A smile passes over Jansen’s face when asked what would happen to the coffee cup on his desk at more than one thousand degrees. “Porcelain is indeed a material that is quite stable at high temperatures,” he explains patiently, “but the cup would ‘flow’ under a mechanical load even at relatively low temperatures.” This high-temperature creep – similar to viscous honey – is the weakness of oxide ceramics, and reason enough to rule out porcelain and similar materials.

But they have an even worse characteristic: if the cup fell to the floor, it would shatter, whereas a metal container would not. Ceramics are hard, but very brittle. Metals, in contrast, are tough and elastic. If necessary, they give by creeping slightly. They age in a way that is well known, and this is decisive for engineers. This is how an aircraft engine manufacturer can state how long a part can remain in operation before having to be replaced. “Conventional ceramic, in contrast, can fail after one hour,” explains Jansen, “or after a hundred thousand hours.”

**DISORDERED NETWORK MAKES CERAMICS TOUGH**

This brittleness is caused by the microstructure of conventional ceramics: they consist of tiny, fused crystals. In such a crystallite, the atoms arrange themselves in a rather orderly fashion to form a three-dimensional spatial lattice. However, its planes, in which the atoms stack up like stories of a building, act like predetermined breaking points. When overloaded, they tear open like the seam of a piece of cloth. When the fracture finally reaches the neighboring crystal, it rapidly forge ahead. “It propagates at the speed of sound,” is how Jansen explains the sudden failure of ceramics.

Although metallic materials also consist of small crystallites, the chemical bonds between the metal atoms behave more like strong, viscous glue. The crystal planes can thus slide past each other under stress without tearing apart. This ductile behavior cannot be transferred to ceramics, because a different type of chemical bond keeps the atoms together here.

So Martin Jansen had to come up with a new concept, which he wrote down already back in 1989 when he was still a professor at the University of Bonn. One key to the new material was the radical abolition of the small crystals. The chemist wanted to develop an amorphous ceramic instead. In amorphous materials, such as types of glass, the atoms form a rather disordered spatial network. Where there is no lattice plane, there is no predetermined breaking point, Jansen thought to himself. This led him to hope that such a ceramic might not fail suddenly due to a brittle fracture – as material scientists would say – but would be impact resistant.

However, atoms tend to form orderly crystals when the melt cools down. This is because they save the most energy in the state of highest order. Only if something strongly interferes with their choreography as they cool down do they remain stuck in an amorphous network. Jansen called on his experience as a chemist to finally select a compound of the elements silicon, boron and nitrogen. A mixture...
with a ratio of 3:3:7 brings about the desired interference with the crystalline sorting process.

The silicon atoms (Si) want to hold their neighboring atoms with four bonds, like chemical “hands” – boron (B) and nitrogen (N), in contrast, play a three-handed game. The non-integer ratios present the atomic ballet with an insoluble problem – how to grab a partner’s hand with each chemical hand, and at the same time dance into a crystalline order. In the end, almost every hand has grabbed another – but the atomic ballet finishes up as a disorderly knot in the desired network. “The atoms are not intelligent enough to solve this problem,” remarks Jansen.

MANY BONDS STRENGTHEN THE ATOMIC CHAIN LINKS

Two further ideas are behind the choice of the chemical bond: every atom in the new Si$_3$B$_3$N$_7$ is bonded to its neighbor via three covalent bonds – four in the case of silicon. This ensures that the energy that keeps the network together is mainly in the bonds between atoms that are direct neighbors, making every atom a strong link in the chain. The second idea is that the high number of bonds also means that an atom can
hardly leave its position. Doing so would require it to break at least two of the neighboring bonds simultaneously, which is very unlikely.

SUSTAINABLE SYNTHESIS FROM RUN-OF-THE-MILL CHEMICALS

This makes the new material resistant to high temperatures, even though it is amorphous. Amorphous materials are assumed to be thermally unstable, which is why Jansen had his work cut out for him convincing the materials scientists. The reason, again, is the energy. If one imagines it as a mountainous landscape, the crystals correspond to the rocks that have rolled down into the deepest energy valleys. However, on their fall into the energy valley, rocks, which correspond to amorphous structures, get stuck in an energy hollow on the slope. If increasing temperatures now shake the energy landscape like strong earthquakes, these rocks tend to jump out of their perilous metastable position again: they roll further into the energy valley, and the amorphous structure reorders itself to form a crystal. The material thus radically changes its properties, which would destroy a machine. In the Stuttgart concept,

Top: A new concept for a new material: Martin Jansen had the idea of producing particularly stable ceramics from a disordered network of atoms.

Bottom: Ceramics on the roll: In the pilot plant at the Fraunhofer ISC, the material is spun into fibers that are much more heat resistant than carbon fibers. They can be used to weave fabrics for composites, for example.
however, the local energy hollows are so deep that the rocks stay inside, and the ceramic material retains its amorphous network.

This project has been aimed at industrial application right from the start. “This is why the synthesis of the precursor molecule was designed to be environmentally and economically sustainable,” says Jansen. All constituents are low-cost, readily available chemicals. The only waste product produced is hydrochloric acid, which can be reused as a chemical.

The manufacture of the ceramic required an unconventional method. The possible solid starting compounds decompose before melting, and after cooling, the desired amorphous network would not be obtained. The network must therefore be constructed step by step from basic molecular components. In the center of these molecules is a nitrogen atom that bonds one silicon and one boron atom. At the edge are groups that act like the components of superglue. In the second step, the “polycondensation,” they allow the basic molecular components to combine in a flash. “This must work like instant glue,” says Jansen. The polymer network thus formed already largely corresponds to the amorphous structure of the ceramic, but residues of glue still remain between the boron, nitrogen and silicon atoms. In the final step, the chemists heat the polymer in order to drive out these residues. Starting at 600 degrees Celsius, the organic substances escape from the network as pyrolysis gas. The pyrolysis is therefore the only step in the synthesis sequence in which material is lost.

Jansen proudly shows one of the results of 20 years of research: the pitch black fiber was produced from the Stuttgart ceramic by the Fraunhofer Institute for Silicate Research (ISC) in Würzburg, a longstanding cooperation partner. It is surprising that this fluffy material is a ceramic – and that it withstands temperatures above 1,500 degrees Celsius without significant loss of mechanical strength. The new ceramic can be processed in many different ways. It can be ground to a powder, for example, that can be sintered at high temperatures to produce components.

“It is also possible to manufacture coatings or infiltrations,” says Jansen, “and to draw these fibers here.” They are the most developed. At the ISC it is possible to witness how they are manufactured: the Würzburg-based researchers built a pilot plant for this, an intermediate step between laboratory and industrial production. This is where they draw the initially colorless ‘green’ fibers out of the polymer before heating them in an oven. Today, the plant already manufactures 50 kilograms of polymer per run. “We have improved the synthesis again and again, changed the constituents and thus significantly improved the yield and the purity of the ceramic,” says Dieter Sporn, who headed the project at the ISC for many years.

One variation of the fiber whose network also contains carbon in addition to silicon, boron and nitrogen has proven to be particularly heat resistant. This SiBNC fiber withstands temperatures of up to 1,500 degrees Celsius in air without chemically decomposing. “No mass loss occurs in helium, even at temperatures of up to 2,000 degrees,” explains Jansen. The new fiber is thus significant.

No highway for cracks: In a conventional ceramic, the fissures propagate rapidly through the atomic crystal lattice (top left) and then jump to the neighboring crystal (right). These predetermined breaking points are absent in disordered amorphous networks (bottom left).
ly superior to expensive ceramic fibers made of silicon carbide (SiC), which are already commercially available. Although it reacts just like these in air with oxygen at 1,500 degrees Celsius, it forms a double layer that protects it from the aggressive oxygen. “The commercial SiC fiber, in contrast, simply corrodes through,” says Jansen.

MATERIAL FOR COATED TURBINE BLADES

The scientists have proven that the ceramic fiber satisfies the demands of turbine construction. It not only withstands higher temperatures than any metallic material, but it remains mechanically stable in the process. “Compared with other materials, its strength is only average,” says Jansen. “But it almost maintains it even at just over 1,400 degrees Celsius, and is therefore better than all other known materials under these conditions.” A turbine blade made from a ceramic composite with this fiber would weigh only one-third of one of today’s blades made of high-alloy steel. The centrifugal forces would thus be correspondingly lower. Moreover, lighter aircraft engines would save kerosene.

Top: How great is the heat shrinkage? One of the two crucibles on the white holder contains the ceramic precursor. Both crucibles are heated with the oven above. A scale at the foot of the apparatus measures the mass loss of the sample. The temperature difference between the two crucibles reveals details of the chemical conversion.

Bottom: The X-ray diffractometer determines the crystalline structure of the material. If it is not visible, that is positive: the ceramic is then amorphous.
The scientists have proven that the ceramic fiber satisfies all the demands of turbine construction. It not only withstands higher temperatures than any metallic material, but also remains mechanically stable in the process.

However, it is not possible to simply “weave” a turbine blade from the fiber. The scientists in Stuttgart and their cooperation partners have thus developed a composite: a ceramic made from silicon carbide through which parallel SiB-NC ceramic fibers are drawn to provide reinforcement. The most promising approach by far is in the use of ceramic fiber reinforced ceramics to overcome the most critical weakness of this class of materials – their brittleness. In principle, the fibers can be processed like carbon fibers to create composites. The company SGL Carbon in Wiesbaden specializes in just this, and the Fraunhofer researchers have brought them onboard. SGL Carbon plans to produce the fibers on an industrial scale for major customers.

A DIFFERENT RECIPE FOR LARGER COMPONENTS

Work is now being done to improve one important aspect of the new ceramic. Although the polymer can easily be formed into larger components by injection molding, the researchers have thus far been successful in producing only the thin ceramic fibers without defects. Thicker material suffers from high shrinkage, because the organic components vaporize during the firing; the escaping pyrolysis gas causes fissures and holes. Jansen’s team is therefore trying to redesign the polymer chemically so that the organic components remain trapped in the network of the atoms during the firing. They can now report some success: Jakob Wilfert, a doctoral student, proudly hands a laboratory visitor a small piece of ceramic. It is about the size of a fingernail and a few millimeters thick. Its shiny black surfaces contain virtually no bubbles.

“One can rightfully say that this is a new class of material,” says Jansen with satisfaction. After all, he has had to suffer a number of disappointments relating to industrial partners. The Bayer Group, for example, backed out in the 1990s after a partnership of many years. Jansen has experienced that the road from scientific invention to technical application can be a very long one indeed. This applies especially to new high-tech materials for use in aircraft engines, for example. They are required to be tested for many years to establish their safety, so investors have to think long-term.

In 2004, Jansen was awarded the Science Prize of the innovation agency for the German science system (Stifterverband der deutschen Wissenschaft) for the development of the new high-temperature ceramic. Last year, the scientists in Stuttgart and their cooperation partners were even nominated for the German Federal President’s Future Prize. “We managed to get into the final eight,” remarks Jansen, but adds with regret: “It was a bit too early, because the ceramic is not really on the market yet.” Jansen is convinced that the new class of material will achieve a high market volume one day. “At the moment, only high-value applications are possible,” he says. “But the material can, in principle, be used for a very wide variety of applications, similar to steel.”

GLOSSARY

Oxide ceramics
Ceramics that contain oxygen in addition to various metals, such as aluminum or zirconium, for example.

Amorphous ceramics
Unlike conventional ceramics, which consist of small, regularly ordered crystallites, the atoms in amorphous ceramics bond to form a disordered spatial network.

Covalent bond
A chemical bond between two atoms. It is formed by at least one electron pair, to which both atoms contribute one atom each.

Polycondensation
A chemical reaction in which small molecules combine to form a multi-link chain or an extensive three-dimensional network. The by-products are simple chemical compounds, such as hydrogen chloride or water.
Clean, efficient and reliable— that's how the power of the future should be. An example of this is the electric current generated by fuel cells fed with biomass. Researchers from the Max Planck Institute for Dynamics of Complex Technical Systems, the Fraunhofer Institute for Factory Operation and Automation IFF, and the Fraunhofer Institute for Ceramic Technologies and Systems IKTS are smoothing the way from the farm to the electrical outlet.
The Max Planck scientists are looking to generate electricity as efficiently as possible using wood chips or straw. That is set to become an important substance in bringing power to the electrical outlet. The puzzle pieces are packed in three dozen little tubes filled with a reddish substance and adorned with chemical formulas, indications of size, and cryptic combinations of numbers. It takes an expert to decode the descriptions scribbled on the tubes in thick marker.

Peter Heidebrecht picks up one of the puzzle pieces. He holds the tube against the light and shakes it gently. The dirty red powder rises in a cloud of dust. “This substance is just one of many options we are currently investigating,” says the process engineer. “But it's this variety that makes the project exciting.”

The project is called ProBio, and the only thing the researchers know so far is the kind of picture the completed puzzle should eventually produce. Heidebrecht and his fellow researchers from the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg have been working on it for three years. They aim to demonstrate a method for generating electricity from biomass as efficiently as possible. However, determining how the individual pieces of the puzzle should look and, especially, how they fit together, remains something of a challenge for the researchers. The composition of the reddish powder that is set to become an important substance in bringing power to the electrical outlet is only a small part of a much larger puzzle.

There is no doubt that biomass will play a significant role in the future. In fact, biomass already accounts for 7 percent of Germany's energy consumption — by far the largest share of all the renewable energies. The German government aims to meet 18 percent of the country's energy demand with renewable sources by 2020. “The challenge of converting biomass to electricity is thus extremely relevant today, and significant for the future,” says Kai Sundmacher, Director at the Magdeburg-based institute and spokesman for ProBio, a joint project being carried out by the Max Planck Society and the Fraunhofer-Gesellschaft. “Even though biomass is not the only solution for the energy supply of the future, it can certainly make a substantial contribution.”

But there are many ways to get power to the electrical outlet. Biomass can be burned, fermented or gasified. The resulting products can be used to operate steam turbines, gas engines or fuel cells. Each variant has its advantages and drawbacks. Many of the methods are well studied, while others are still virgin territory, technologically speaking.

Like the fuel cell at the center of the ProBio project. Fuel cells are small power plants that directly convert the chemical energy stored in a gas to produce electrical energy. “Of all the energy converters at our disposal, fuel cells promise the highest level of efficiency,” says Peter Heidebrecht. To date, such cells are mostly fed with natural gas, methanol or pure hydrogen. In principle, however, there is no reason why they can’t be fed with clean gas from biomass — provided the right pieces of the puzzle can be fitted together.

FUEL CELLS INCREASE THE ELECTRICITY YIELD

When it comes to handling the biomass, the Max Planck researchers are not exactly taking the easiest road, either: “The potential of simple combustion has been exhausted,” says Heidebrecht. Combustion burns biological raw materials and the heat released is used to generate electricity. “This process has upper limits set by the laws of thermodynamics. And no matter what engineering tricks you use, you just can’t change them,” says Peter Heidebrecht.

Fermentation — the process by which microorganisms decompose biomass in an oxygen-free environment and convert it into gas — has its drawbacks, too: the raw materials, such as wood and straw, contain a large proportion of a substance called lignocellulose. Bacteria aren’t quite sure what to do with it. It is hard to digest, so it doesn’t go down very well. Moreover, it is a slow process, and there is noth-
where the biomass is introduced – by a spiral conveyor. The conveyor is water-cooled, as the fuel is intended to break down in the reaction zone – which is heated to 800-850 degrees Celsius – and not before it gets there.

BIOMASS DIVERSITY COMPLICATES MATTERS

Insulated pipelines with a silvery sheen conduct the fuel gas produced to the analysis equipment in the Fraunhofer lab. In a future ProBio power plant, the researchers want the gas to move directly into the fuel cells after it has passed through various cleaning stages. Then everything will be much bigger, too. A fluidized bed gasifier for a power plant with an output of several megawatts would have to be about one meter in diameter, whereas the pipe in the Magdeburg lab measures a mere five centimeters across. “This scale is sufficient to enable us to study the conversion of the biomass in the fluidized bed,” says Thomas. “But the amount of fuel gas produced would be insufficient for a pilot plant.”

Fluidized bed gasification is actually not a new idea. It was devised back in the 1920s for the purpose of extracting synthesis gas (syngas) from coal. However, petroleum chemistry soon made the process superfluous. Yet coal has one important advantage over biological waste: its main component is always the same – carbon. “Nevertheless, one type of biomass is not the same as another,” says Thomas.

Glass jars holding wood pellets, oilseed rape straw, biomass coke and ja-tropha, a member of the spurge family of plants and a popular source of biomass in Asia, stand next to the fluidized bed gasifier.
In the puzzle that is ProBio, each substance has been extensively tested—with various gasification agents, at different temperatures and for different residence times in the fluidized bed. The composition of the gas changed each time. Even the season, the age of the wood and the way it was stored affect the quality of the gas. “Biomass is simply not a pure substance; it’s a complex composite mixture,” says Kai Sundmacher. “That’s part of what makes our project so interesting.”

Ideally, the gas that escapes from Sascha Thomas’s furnace is colorless and therefore free of impurities. However, it usually has a yellowish tinge, indicating that it contains tar, dust, and halogen and sulfur compounds, all of which fuel cells dislike—they contaminate their electrodes and must therefore be removed from the gas.

This is normally done by scrubbing systems in which jets of water are sprayed into the gas, promptly cooling it to room temperature and flushing out the contaminants. What remains is cold gas and lukewarm water. “The problem with the cold gas is that it would first have to be reheated to 800 degrees Celsius for the subsequent steps,” says Peter Heidebrecht.

So the ProBio scientists thought up another method for their process: they pass the gas through a packed bed of ceramic beads to which any dirt particles adhere. “The way it works is similar to groundwater seeping through layers of sand and getting purified in the process,” explains Sascha Thomas. Catalytically active packed layers simultaneously convert the unwanted tar compounds into additional fuel gas, thus increasing the energy content of the gas. Finally, halogens and sulfur are removed with metal oxides. These react with the toxic components at fairly high temperatures.

What remains is a gas that contains clean hydrogen, but also large amounts of carbon monoxide. That can be good or bad, depending on the type of fuel cell the gas is feeding: high-temperature fuel cells, such as solid oxide fuel cells (SOFC), are robust energy converters that can take any fuel. They have a ceramic electrolyte, function at about 800 degrees Celsius and can even make electricity out of carbon monoxide. They run best at a constant load around the clock, and do not react well to sudden changes in the electrical demand.

FOOD FOR MANY DIFFERENT FUEL CELLS

“The temperatures inside the cells must remain within a certain window,” explains Peter Heidebrecht. “Any change in load alters the temperature profile and can damage the cells.” Moreover, the high-temperature fuel cells being studied by the Fraunhofer IKTS in Dresden take several hours to days to reach operating temperature, depending on their size.

Things are different with low-temperature cells, known as PEM (polymer electrolyte membrane) cells. These cells are flexible but sensitive. Their electrolyte consists of a polymer membrane, which means it can’t withstand temperatures above about 80 degrees Celsius. However, the cell’s power output can be adapted to changing electricity demand at a hour’s or even a minute’s notice, if need be. This flexibility comes at a price, though: low-temperature fuel cells are almost completely incapable of handling carbon monoxide. Any concentration of more than 0.01 parts per thousand is highly detrimental to the cell, causing the electrical power output to plummet.

The process engineers in Magdeburg were assisted in their search for the matching piece of the fuel cell puzzle by happenstance—and a dusty red powder: “We really only wanted to remove the carbon monoxide from the combustion gas,” recalls Peter Heidebrecht. The stream of gas can contain up to 20 percent of the substance that is either toxic or useful depending on the type of fuel cell. The researchers attempted to bring it under control with dirty, reddish iron oxide—rust, basically: when the gas, heated to 800 degrees, flows over an oxide powder of this kind, the powder liberates some of the oxygen atoms the powder lattice contains and passes them on to the carbon monoxide. Carbon dioxide is formed, which is harmless to even a low-temperature fuel cell. The problem is that, whatever the scientists do, the gas still retains large quantities of carbon monoxide. Too much for a PEM fuel cell. Moreover, the iron oxide also converts the badly needed hydrogen into useless water.
However, the powder turned out to be very useful, thanks to a different kind of strength: once the powder lattice has shed its oxygen atoms, it greedily tries to replace them. Steam is one of the things that can provide them. When the steam comes into contact with the depleted iron oxide, the powder recclaims oxygen from the water molecules. What is left over is pure hydrogen – ideal for a low-temperature fuel cell.

**WANTED: A DURABLE SUBSTANCE FOR GAS SCRUBBING**

“When we saw that, we knew this kind of method would be wonderfully suited for gas separation,” recalls Peter Heidebrecht. In the first round, when the combustion gas flows over the iron oxide, the mixture that is left over is something with which high-temperature fuel cells can live very happily indeed. The second step, when it is flooded with steam, produces the virtually pure hydrogen for the low temperature cells.

There is still a great deal to be done: “If we use iron oxide alone, the oxygen exchange takes a heavy toll on the material, and the amount of hydrogen we get out of it quickly diminishes,” says Liisa Rihko-Struckmann, who is coordinating the ProBio project at the Max Planck Institute together with Peter Heidebrecht. That is one of the reasons for the many different powder samples in the acid yellow stands in the lab rooms in Magdeburg. Many contain nothing other than the red iron oxide particles measuring between one-tenth and five-tenths of a millimeter, while others have had aluminum oxide or silicon oxide added, though the most common additive is cerium-zirconium oxide.

The researchers heat each sample to 800 degrees Celsius in one of the lab furnaces and then test it with a carefully mixed gas. “Right now we are taking particular care to ensure that the materials are stable and can be used for a lengthy period,” says Rihko-Struckmann. The powders should be able to withstand a thousand gas and steam cycles.

Samples that produce a positive result in the lab are given a chance to prove their worth in the pilot plant lab, a gray cube at the northern end of the Max Planck Institute. This is where the engineers have built a test apparatus – a heatable steel pipe that they fill with roughly 20 centimeters of the iron oxide mixture. Instead of the 250 milligrams used in the lab, the researchers here need 100 grams of the substance.

“We are currently working on making larger particles out of our pretty fine powder, so that the gas can stream around them,” says Liisa Rihko-Struckmann. Afterward, the process engineers intend to study how the gas diffuses within the powder, how to make optimum use of the oxygen in the oxide powder, and how the timings for switching between fuel gas and steam ought to be arranged. “These kinds of dynamically operated processes are some of the things our institute has been working on for years now,” says Kai Sundmacher.

Gas purifiers in the Max Planck pilot plant lab, fluidized beds and packed beds at the Fraunhofer Institute, fuel cells in Dresden and Magdeburg – the pieces of the puzzle that comprise a potential ProBio power plant are still widely scattered. The only place they come together at the moment is in a computer’s circuits, where the components – based on the values measured in the lab – can be simulated, combined and appropriately altered.
With the possible improvements they have identified on the computer, the researchers return to the reactor, “hoping that everything goes as we expect it to,” says Peter Heidebrecht with a chuckle. “Of course, that’s usually not the case on the first try.” They feed the mathematical model with the new findings from the lab in an effort to optimize the experiment even further. It is a constant back-and-forth that gradually brings them closer to producing a real power plant.

MODEL POWER PLANT OF INCREDIBLE EFFICIENCY

The process engineers have simulated more than one hundred different variants over the course of ProBio. What they discovered is something no one would have expected at the start of the three-year project: in the optimum power plant, both types of fuel cells work in parallel—in practice, providing the red powder can split fuel gas into one highly pure and one less pure stream of gas. “That’s a kind of combined power plant,” says Peter Heidebrecht. “It delivers a broad range of products spanning electric base load, dynamic peak load and usable waste heat.”

Above all, it works with almost unbeatable efficiency. For their simulation, the engineers selected a model power plant designed for biomass with a calorific value of just under 19 megawatts, equivalent to slightly more than one kilogram of wood per second. The fluidized bed gasifier, purification in packed beds, hydrogen splitting and parallel operation of high- and low-temperature fuel cells boost the final output to almost 9 megawatts of electric power—an electrical efficiency of nearly 50 percent. Traditional biogas plants with an internal combustion engine attain just 35 percent. “These days, an improvement of even a few percent is cause for celebration because it helps save an awful lot of energy in the long run,” says Liisa Rihko-Struckmann.

Even though the ProBio project, which the two research organizations funded with 4.2 million euros, officially ended early this year, the researchers plan to continue on their own. A pilot power plant is currently being built at the Fraunhofer Institute in Magdeburg and is scheduled to go into operation in the summer. “Then the individual components we’ve gathered experience on to date can finally be studied together and on a larger scale,” says Sascha Thomas.

The researchers at the Max Planck Institute, already dedicated to the study of complex chemical processes and related basic research, will also continue working on the individual pieces of the puzzle, including the fuel cell and the dusty red powder. “Even the highest efficiency is useless if the equipment lasts only a matter of hours or days,” says Kai Sundmacher. Therefore, they will primarily be fine-tuning the operating conditions and the materials in an effort to engineer in a significant prolongation of the lifespan. The researchers still have a couple of pieces to fit together in the big puzzle called ProBio.

GLOSSARY

Lignocellulose
Cellulose that is stabilized by lignin. It makes up the walls of wood cells, which gives wood its mechanical strength.

Fluidized bed gasification
This process creates fuel gas from coal or biomass. The solid components are usually fluidized and heated with a substrate. Hydrogen and carbon monoxide are two of the gases produced during chemical reaction with steam or another gasification agent.

Syngas
A gas rich in hydrogen and carbon monoxide that is produced during the gasification of coal with steam and is suitable as a source material for chemical synthesis.

Solid oxide fuel cell, SOFC
The solid oxide or high-temperature fuel cell owes its name to the ceramic material that makes up its electrolytes and that is permeable to oxygen ions but not electrons. At temperatures of up to 1,000 degrees Celsius, it generates electricity highly efficiently and is not sensitive to carbon monoxide.

Polymer electrolyte membrane fuel cell, PEMFC
The two poles of this low-temperature fuel cell are separated by a membrane that only protons can cross. The PEM fuel cell provides flexible power output. However, it tolerates carbon monoxide very badly because this gas blocks the surface of the electrodes, making them inaccessible to the reactants responsible for the cell reaction.
Tobacco’s solar power plant: One of up to 100 chloroplasts from the cell of a tobacco leaf. Its interior is filled with stacks of flat membrane discs (thread-like structures) that contain the molecular machinery responsible for photosynthesis. Like mitochondria, chloroplasts have their own genome (light-colored areas).
Powerhouse in the Foliage

Photosynthesis, a veritable stroke of genius on the part of nature, makes the existence of higher life forms possible. If it can be optimized, it may be able to make an even greater contribution to the resolution of future energy problems. Manajit Hayer-Hartl and Ulrich Hartl are currently working on this possibility at the Max Planck Institute of Biochemistry in Martinsried.

TEXT HARALD RÖSCH

Be honest – when you look at a rich green meadow, does a solar power plant come to mind? Of course not. However, plants do something very similar: they convert the energy from sunlight into usable energy. Through photosynthesis, they harness this energy to synthesize sugar in a process that involves numerous intermediate steps. We already tap into this energy source today, for example in the form of biofuel and in biogas plants.

So nature has been building solar power plants for millions of years. The only drawback is that these natural power stations work so inefficiently. Plants are energy wasters – at least when it comes to harnessing energy through photosynthesis. The combined area of Germany and France would not provide sufficient acreage to cover Europe’s bioethanol or biodiesel requirements in 2050. If, however, 10 percent of the energy that falls on this area in the form of sunlight could be converted into chemical energy, an area the size of the German federal state of Baden-Württemberg would probably be sufficient.

The efficiency of plant photosynthesis is only around 5 percent. In comparison, the solar power cells available today have an efficiency of around 20 percent, but they don’t produce fuels that, like bioethanol, can be easily stored and transported. However, there are organisms that achieve far greater levels of efficiency than plants. The green sulfur bacterium Chlorobaculum tepidum, for example, has extremely efficient solar power equipment for the absorption of light, and can convert 10 percent of incident light into chemical energy.

TURBO PLANTS HARNESS MORE ENERGY

For this reason, scientists are working on developing ways to make photosynthesis more effective. Their aim is to optimize various steps in the process of the conversion of light energy into chemical energy, for example by increasing the efficiency of the photosynthesis machinery.

Plants that have been upgraded in this way would be capable of forming more biomass for the purpose of fuel production. In contrast to this, some scientists want to dispense with plants altogether and equip bacteria with an optimized photosynthesis device instead. Another possible approach will be independent of the services of any kind of organism: hydrogen, for example, could be generated in bioreactors in which photosynthesis takes place using just a few necessary proteins. Nature has, in fact, created enzymes that can split water with the help of solar energy and that could thus replace costly platinum in fuel cells. And nature also has enzymes that subsequently produce hydrogen from the water fragments (see MaxPlanckResearch 3/2006, page 32 ff.).

At the Max Planck Institute of Biochemistry in Martinsried, near Munich, researchers are looking for a way to make plant photosynthesis more effective – and have already made significant progress toward achieving this objective. The scientists working with Manajit Hayer-Hartl have discovered the folding process of a key protein in photosynthesis, known as Rubisco. Armed with this knowledge, the re-
That is why the Martinsried-based researchers want to modify Rubisco in such a way that it can bind only carbon dioxide. To do this, they must first establish how the protein is actually formed. Rubisco is one of the largest of all proteins and consists of eight large and eight small subunits. “With so many subunits, there is a significant risk that the wrong parts of the protein will aggregate and clump together,” explains Manajit Hayer-Hartl. In order for the protein to function correctly, the amino acid chains must be correctly folded and the subunits assembled so that they form a cylinder. This complex folding process is managed by special proteins known as chaperones.

According to the researchers, three proteins are required to recreate a functional Rubisco complex: in addition to the previously identified chaperonins GroEL and GroES, a recently discovered helper protein (RbcX). RbcX ensures that two large subunits of Rubisco can assemble next to each other. Four of these dimers then form the cylinder, and four small subunits position themselves at the top and bottom areas of the cylinder. “We now understand why, for example, bacteria are not able to produce functional Rubisco. If we insert only the DNA for the protein into the bacterial genome – without the corresponding helper protein – functional Rubisco cannot be formed,” says Ulrich Hartl.

Having achieved this breakthrough, the scientists can now get to work on producing Rubisco artificially in the laboratory. To this end, they want to introduce the DNA for Rubisco, the two chaperonins and the helper protein into bacteria. The rapidly reproducing microorganisms will then produce the Rubisco protein in sufficient quantities. The researchers are seeking to find a more efficient variant of Rubisco with the help of such bacteria. “If we introduce the Rubisco DNA into a bacterial strain that can survive only with functional Rubisco, we can test all possible mutations in the Rubisco gene and immediately establish how well the individual variants work,” explains Manajit Hayer-Hartl.

**CAN HUMANS SUCCEED WHERE NATURE FAILED?**

With the help of this process, multiple mutations can also be generated and studied in different positions in the Rubisco gene. This is an important advantage, as it may not be possible to further optimize the protein by replacing a single amino acid. This would explain why nature itself did not adapt Rubisco to the increasing oxygen content in the air over the course of evolution. Some scientists believe that nature has already found the optimum structure for Rubisco, and that Rubisco cannot be improved. The scientists in Martinsried disagree. They are convinced “that the Rubisco molecule of plants is definitely not the best possible variant. Some red algae have a more efficient form. This suggests that the plant enzyme can be improved, too.”

However, finding mutations that would render Rubisco more specific to carbon dioxide is not the only challenge the scientists have to face. The new results show that nothing will render Rubisco more specific to carbon dioxide. To do this, they must first establish how the protein is actually formed. Rubisco is one of the largest of all proteins and consists of eight large and eight small subunits. “With so many subunits, there is a significant risk that the wrong parts of the protein will aggregate and clump together,” explains Manajit Hayer-Hartl. In order for the protein to function correctly, the amino acid chains must be correctly folded and the subunits assembled so that they form a cylinder. This complex folding process is managed by special proteins known as chaperones.

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However, finding mutations that would render Rubisco more specific to carbon dioxide is not the only challenge the scientists have to face. The new results show that nothing will work without the matching molecular chaperones. Unlike Rubisco itself, RbcX works extremely selectively and also assists in the folding of the natural plant Rubisco. For this reason, it has not been possible, for example, to transfer the
An organism that needs light to survive but lives in places where little light is available requires a special antenna. The green sulfur bacteria *Chlorobaculum tepidum*, whose habitats include the deep, dark layers of oceans and lakes, have just such antennae. With their chlorosomes, they operate the most efficient solar power plants found in nature: they convert 10 percent of the light energy into chemical energy, namely sugar.

That’s why Alfred R. Holzwarth and his research group at the Max Planck Institute for Bioinorganic Chemistry in Mülheim an der Ruhr are studying chlorosomes with the aim of using the bacterial solar power plant as a model for efficient energy generation. The scientist has already taken an important step toward fulfilling this aim: an international research team, which, in addition to Alfred Holzwarth and Michael Reus from the Max Planck Institute in Mülheim, also included scientists from the universities of Leiden and Groningen, as well as Penn State University in Philadelphia, discovered how the chlorosomes are structured.

The researchers ingeniously combine various experiments and calculations. In this way, they established that the chlorophyll in the chlorosomes piles up to form helices. “A key question up to now concerned the various possible ways in which the individual chlorophyll complexes might be arranged next to each other,” says Alfred Holzwarth. “We have now found the answer.” And not just to this question. Little was previously known about the arrangement of the chlorophyll stacks. Most researchers who are looking to the bacterial solar power plants for inspiration for the biofuel production of tomorrow favored layers – a misconception, as Holzwarth’s research team has now established. “The simple chlorophyll helices are, in turn, twisted into a helix and thus form a tube,” he explains. The individual tubes must also subject themselves to another order: several tubes with different diameters are inserted into each other like a telescopic pole.

“Unlike in higher plants, this complex hierarchical structure arises on an entirely self-organized basis,” says Holzwarth. In higher plants, proteins step in as mediators. “As the chlorosomes contain only chlorophyll, they provide suitable models for self-organizing technical light antennae,” he explains. It is extremely difficult to imitate the proteins in the chloroplasts of higher plants.

Before Alfred Holzwarth and his colleagues can copy the antennae for technical purposes, they must first resolve some fundamental issues. “We want to find out more about how light absorption in the chlorosomes works,” says Holzwarth. This is the only way the search for artificial antennae with a similar level of efficiency has any prospect of success. And this would be only the half-way mark in the quest for a way to efficiently bind solar energy in biofuel, as Alfred Holzwarth explains. “We have to couple the antennae to a simple system that converts the captured light energy into chemical energy – that is, a system that, like photosynthesis, develops sugar from carbon dioxide or splits hydrogen from water.”

*Peter Hergersberg*

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**BLUEPRINT FOR A BACTERIAL SOLAR POWER PLANT**

The chlorophyll in *C. tepidum*’s chlorosome arranges itself in spirals that form concentric tubes (green ring: detailed view).
red-algal Rubisco to plants – it simply does not fold correctly in this case. It is thus possible that an optimized Rubisco variant will also require its own specific assembly chaperone.

MORE ENERGY WITH LESS WATER

Despite all the difficulties it presents, the objective behind this research is worthwhile: on the one hand, algae or plants with an optimized Rubisco variant could be used as a weapon in the fight against the rising carbon dioxide concentration in the atmosphere; on the other hand, the availability of such turbo plants with a significantly higher growth rate would also be a huge advantage for agriculture. “We could benefit from a form of Rubisco that is 10 or 15 percent more efficient,” says Manjit Hayer-Hartl. It is not just a question of accelerating growth, but of even making it possible in the first place in some locations, as more efficient conversion of carbon dioxide into sugar reduces the plant’s water consumption. As a result, in the future, agricultural activity would be possible in areas that are currently too arid for today’s crop plants – and such areas are set to expand further due to the increasing scarcity of water on Earth.

GLOSSARY

Chaperone
Proteins can function only if their amino acid chains are correctly folded. Like the chaperones of the 19th century whose job it was to shield young ladies from improper influences, special enzymes in cells ensure that proteins do not end up on the wrong path and assume the wrong form. Some chaperones take the form of a cylinder in which only a single molecule can fold. Such chaperones found in bacteria, chloroplasts and mitochondria are known as chaperonins. A lack of functional chaperones can result in the clumping of proteins and cause various diseases, such as Alzheimer’s and Huntington’s chorea.

Photosynthesis
Photosynthesis involves the production of carbohydrates from carbon dioxide and water with the help of solar energy. The process can be subdivided into two connected stages: The light reactions (photo part) make energy available for the water to be split into electrons, protons and oxygen. The energy-rich electrons and protons are used in the Calvin cycle (synthesis part) to convert carbon dioxide into sugar.
Die auflagenstärkste hochschul- und wissenschaftspolitische Zeitschrift Deutschlands.
Leseprobe unter: www.forschung-und-lehre.de
oder per Fax 0228 902 66-90
The Earth’s atmosphere is extraordinarily thin – and it is in serious danger. Consequently, researchers are working on methods to counteract anthropogenic climate change. At the same time, a legal framework for such large-scale experiments must be established.
The global climate is changing – the world is facing global warming. Researchers are working on technologies to fight the causes and impacts of anthropogenic climate change. Yet, are such methods – if they even work – compatible with international law?

Researchers such as David Reichwein at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg are investigating just that.

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above all, it will take effect quickly in an emergency. One argument often cited for the latter is the 1991 eruption of the Pinatubo volcano: it released around ten million tons of sulfur dioxide into the stratosphere, where chemical processes converted some of it into sulfate particles. The researcher believes that these tiny airborne particles resulted in an average drop of 0.5 degrees Celsius in temperatures on Earth the following year.

However, opponents of climate therapy through sulfur dioxide cite the imponderability of the risks of this model. “No one knows yet precisely what impact such an experiment might have on the global climate system and how differently individual regions would be affected,” says legal scholar David Reichwein, who is exploring the legal boundaries and the regulation of geoengineering for his dissertation at the Max Planck Institute for Comparative Public Law and International Law.

Favoring this method, in the opinion of its proponents, is the fact that it is economical, it is technically feasible with a minimum of complications, and a greater number of water drops in the clouds. This would make the clouds significantly brighter and they would thus reflect more sunlight.

One of the climate engineers’ clear favorites, however, is Chemistry Nobel laureate Paul Crutzen’s proposal that caused quite a stir some four years ago: bringing sulfur dioxide into the upper stratosphere, where it oxidizes to form sulfuric acid, which in turn condenses into small particles. The idea of forming a kind of sunshade over the Earth led to vigorous disputes among researchers and in the media.

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In his research, Reichwein uncovered, for example, a variety of significant studies that address the undesired side effects of climate therapy through aerosol screens in the stratosphere. As an example, he cites a study from November of last year: based on their models, Patricia Heckendorn from the Institute for Atmospheric and Climate Sciences at the ETH Zurich and her colleagues conclude that the use of stratospheric sulfur aerosols could result in a considerable breakdown of the ozone layer.

According to Reichwein, after the volcanic eruption in the Philippines in 1991, shifts in rainfall areas were also observed, which could certainly be among the undesired side effects of a large-scale climate experiment.

A CODE OF CONDUCT FOR RESEARCH

The consequences of such an event could be devastating – at least for the people who live in those regions, who suddenly find themselves high and dry, or whose fields are flooded after torrential rainfalls. “The problem here is that we can’t simply test the results in experiments, as not all risks are detectable on a small scale or in simulations,” says David Reichwein. “The consequences become apparent only with the first large-scale deployment.” Moreover, the aerosol injection, in any case, would have to be done over an extend-
ed period in order to avoid potentially causing even faster warming after the injections are stopped.

This uncertainty regarding the risks and consequences of systematic technological interference in the planet’s climate system applies to nearly all geoengineering proposals, says Reichwein. The 24-year-old international law specialist is part of the team of young researchers who are critically examining the various ideas for easing the climate crisis in the context of the project “The Global Governance of Climate Engineering” at the University of Heidelberg’s Marsilius Kolleg. In this project, researchers work across disciplines and focus on the diverse relationships between technological, economic, cultural, political, social, psychological and legal aspects.

Their common goal is to consider, through dialogue and from a number of perspectives, the opportunities and risks of a controlled global climate, and to develop a code of conduct in research for incalculable side effects of the potential methods. “Among other things, we are concerned with the technical and economic feasibility of the proposals,” says Reichwein. Furthermore, they want to examine how global climate models can be linked with geographic and socio-economic data.

To this end, the environmental physicists in the Kolleg are focusing on devising and comparing realistic scenarios for various methods, especially for artificial cloud formation. Philosophers and psychologists are shedding light on how geoengineering technologies are perceived by the public and how willing people are to invest in them. Economists are studying game theories on costs and benefits, as well as the economic feasibility of the technologies. Human geographers and political scientists are delving into public discourse, political strategies and the spatial distribution of the consequences of geoengineering measures.

Based on its experience in international environmental law and the law of the sea, the Max Planck Institute for Comparative Public Law and International Law is the only non-university research facility participating in the University of Heidelberg’s Marsilius project. The project is supervised by Rüdiger Wolfrum, one of the Institute’s two directors. This was prompted by a legal opinion on the admissibility of the iron fertilization research. Reichwein’s role in the joint project is to model a possible international agreement from a political, economic and legal perspective.

To what extent are the geoengineering research and models reconcilable with international law? That is one of the questions Reichwein will be addressing over the next three years. “I just find it interesting to think in broad categories,” says the Max Planck researcher, explaining his preference for global issues. He chose to focus on European and international law even while still studying at Bucerius Law School in Hamburg. He was aware right from the start that he was treading new legal territory with this project.

Half a year ago, however, Reichwein did not yet know just how far beyond the foundation of sure facts and laws this field lies. Describing the vague background of his research, he says, “The only thing that is certain here is that nothing is certain.” This uncertainty is not limited to the technical feasibility and the side effects of targeted climate manipulation, but also extends to the legal level: “Geoengineering has not yet found its way into international treaties.”

GAPS IN INTERNATIONAL LAW

In view of the global dimensions and the high risks of these climate manipulations, an entire array of fundamental questions on the legitimacy of relevant technologies need some deliberative answers. “For example, how can it be ensured that decisions to deploy any given method are made on a solid scientific basis?” says Reichwein. As yet, international law has no precept for this fundamental question. Furthermore, there is an urgent need to clarify who should have the right to implement such potentially conseq-
The Lohafex experiment made the ocean bloom. Fertilized with iron sulfate, the algae flourished (circle on the satellite image, left), but they were devoured by small crustaceans. Conclusion: climate experiments definitely can have undesired side effects – and for this and other reasons, require a binding legal foundation.

The Ph.D. candidate hopes that his work will help establish clear and transparent terms, at least on the legal level. In addition to legal literature, he has been reading up on the scientific basis of geoengineering since December 2009. Commenting on his efforts to bring his scientific and technological knowledge up to date, he remarks that it is sometimes some pretty heavy stuff. He says the talks and workshops with the other doctoral students in the Marsilius project, which are held every two weeks, are very enlightening. “A lot of my questions are answered there. The approach from various viewpoints is helpful and interesting,” says Reichwein.

But the open international law questions are something he has to address on his own. “In doing so, I have to differentiate between the various envisioned actions,” he says, describing his approach. It is about evaluating, from a legal perspective, whether existing international treaties or international customary law forbid targeted active influencing of the climate or make other legally binding statements about it. “For the use of sulfur sulfites in the stratosphere, some treaties that must be considered include the ENMOD convention, the Convention on Long-range Transboundary Air Pollution, and the Vienna Convention for the Protection of the Ozone Layer,” says Reichwein, naming some examples from existing law that apply, at least in part, to geoengineering.

The London Convention – a Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter –, the UN Convention on the Law of the Sea and the Convention on Biological Diversity, among others, could pose an obstacle to the iron fertilization measures. According to David Reichwein, “The international legal custom of prohibiting cross-border environmental damage must likewise be considered. This prohibits every nation from developing or permitting activities in its territory that could lead to considerable cross-border environmental damage.”

REACHING A CONSENSUS AMONG STATES WILL BE DIFFICULT

In the second part of his dissertation, the young researcher first wants to find the various forms of legal and non-legal governance with global applicability in the context of environmental law. “The selection ranges from multilateral-
al international treaties to unilateral approaches to a complete ban on geo-engineering measures,” he explains. “Then I’ll look to see which could be fitting legal instruments for geo-engineering, how they would have to be structured and what advantages and disadvantages they entail.” In terms of international law, a binding agreement between countries, as well as a follow-up agreement to the Kyoto Protocol for joint efforts to reduce carbon dioxide would certainly be desirable.

However, the fact that this did not succeed during the climate negotiations in Copenhagen clearly shows how difficult it is to reach a consensus in the community of states. “In view of the potential risks and side effects of climate manipulation, and moreover, the fact that they can vary greatly from one region to the next, the process is not likely to be any easier for the geo-engineering methods,” suspects Reichwein. However, the researcher does not consider it to be his job to determine whether such climate manipulation should be permitted in the first place: “That is no more a matter for an international law assessment than is a moral evaluation of such interventions.”

Rather, he and his colleagues want to help ensure that such discussions and decisions on potential measures can take place on legally firm ground. After all, it’s possible that the carbon dioxide reduction measures will not be sufficient. “In that case, the climate activists will need a plan B. And maybe, through my work, I can do my little bit to halt climate change,” says David Reichwein.

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**GLOSSARY**

**Aerosols**
Mixtures composed of airborne particles (aerosol particles) and a gas. The particles play an important role in the formation of cloud droplets and have a major impact on the climate.

**Alfred Wegener Institute**
Named after the eponymous polar researcher and geoscientist, the Alfred Wegener Institute (AWI) was founded in Bremerhaven on July 15, 1980. Its core subjects are marine biology, marine geology and climate research, and it is a member of the Helmholtz Association of German Research Centres.

**Stratosphere**
The atmospheric layer that lies above the troposphere and extends up to a height of about 50 kilometers. In comparison, the stratosphere contains a lot of ozone.

**International law**
A legal order that regulates the relationships between states on the basis of equality.
Winter on the Balcony

Some migratory birds are able to adapt their migration pattern rapidly to climate change.

Migratory birds might bear the brunt of climate change. Not only do they have to undertake strenuous and dangerous journeys between their summer and winter quarters, they also fall behind in the competition with non-migratory birds for territory and nesting places. However, it is possible that, by changing their migratory behavior, at least some species are able to adapt to climate warming more rapidly than previously feared. Francisco Pulido and Peter Berthold from the Max Planck Institute for Ornithology in Radolfzell have discovered that migratory birds can become residents within a very short time, spending winter in their breeding area and no longer migrating. For this purpose, they mated in the laboratory black cap nestlings that were specifically selected for their low migratory activity (measured on the basis of “migratory restlessness”). The duration of migratory restlessness, which is expressed in nighttime flapping and hopping on the perch, is roughly equivalent to the time it takes to fly to winter quarters. As the researchers had deliberately chosen less restless individuals, their offspring exhibited progressively lower levels of migratory activity, and after just two generations, the first resident birds emerged from this population of originally fully migratory birds. A partially migratory population consisting of migratory and resident birds had thus evolved, which, within a few generations, can selectively become a fully resident bird population. Two evolutionary mechanisms are apparently key to the rapid adjustment of migratory behavior to new climatic conditions. First, the reduction (or increase) in the length of migratory activity, and consequently the distance migrated. Second, the shift in the proportions of resident and migratory birds in partially migratory populations to almost fully migratory or non-migratory populations. These mechanisms take effect fastest in short-distance migrants with high percentages of migratory and resident birds, but over time, also in long-distance migrants. (PNAS, April 6, 2010)

Oxygen from the Wonderful Methane Eaters

Up to now, plants and blue algae have had a monopoly on making oxygen. They now have competition – in the form of a recently discovered fresh water bacterium named Methylomirabilis oxyfera (which translates as “wonderful methane eater that produces oxygen”). An international team of scientists showed that this bacterium produces oxygen and does not even need light to do so. While plants and blue algae separate off the oxygen during the photosynthesis of water molecules, Methylomirabilis uses the nitrogen held in nitrite molecules. It does not, however, release oxygen molecules, but uses them to oxidize the slow-reacting methane and produce energy from it. Methylomirabilis benefits from the fact that there are large amounts of nitrite in fresh water from the intensive fertilization of agricultural land. “It is possible that this reaction path is the missing link that made it possible for photosynthesis and oxygen production to evolve billions of years ago,” says Marc Strous from the Max Planck Institute for Marine Microbiology in Bremen. (Nature, March 25, 2010)
**Where Comets Spew Dust**

Scientists identify the active regions on the surface of comets

Comets are dangerous objects to research – at least close up. This is because tiny dust particles that flow into space from the active regions on the surface can damage space probes. It is not easy to determine from the Earth exactly how these fountains originate. Scientists at the Max Planck Institute for Solar System Research in Katlenburg-Lindau have now developed a computer model that locates these regions using photographs taken from the Earth’s surface. They chose an indirect approach that, for the first time, took into account the three-dimensional structure of the comet’s core, and they relied on a standard procedure. Telescope observations of the changes exhibited by the light of a comet as it orbits allow conclusions to be drawn about the shape of the core. The researchers then fed an initial assumption about the locations of the active regions into their program. They also made assumptions about a few physical parameters of the dust particles, such as their size and the speed at which they leave the surface of the core. The computer delivered results in the form of an image similar to one provided by a telescope from Earth. Comparing this with the real telescope image allows the modeled images to be refined until the simulation and the real photograph are the same. This new process could assist in calculating a safe route for the ESA space probe *Rosetta*, which is expected to encounter the Churyumov-Gerasimenko comet in 2014. (*Astronomy & Astrophysics*, 512, A60, 2010)

**A Fingerprint for Genes**

Although cells do not have mouths, they can ingest substances from the external environment. They pick up material from the outside by pinching off bubbles of their cell membrane with which they have enclosed the substances. Depending on the substance they contain, these vesicles, which are also called endosomes, are transported to different locations within the cell, where they are processed or broken down. Scientists working with Marino Zerial at the Max Planck Institute for Molecular Cell Biology and Genetics in Dresden have used a new strategy to identify around 4,000 genes that are directly or indirectly involved in endocytosis. When individual genes malfunction, vesicles remain in the periphery of the cells and do not reach the center. It appears that different materials are directed to their destination by different genes. The enormous number of genes involved reflects the significance of endocytosis in the organism. For example, the production of important metabolic substances such as insulin depends on endocytosis, and viruses use endosomes to infect cells – findings that were made possible through combinations of different techniques. The scientists in Dresden blocked each of the 24,000 or so human genes in turn, using RNA molecules (si-RNAs) that attach themselves to specific sections in the DNA and silence the gene in question. With the aid of fluorescent dyes and automatic image analysis, they were able to assign each gene a specific function in endocytosis and create a quantitative profile of each gene – thus giving each gene an individual fingerprint. (*Nature*, February 28, 2010)
Death of a Star in Three Dimensions

New computer models show in detail how supernovae are shaped

A star dies in 3-D – not in space, but on a computer screen. For the first time, complex calculations have been successfully used to recreate the death of a massive star in three dimensions. The simulations seamlessly cover the period from the beginning of the explosion to the point when the shock wave breaks out of the star’s surface several hours later. The scientists at the Max Planck Institute for Astrophysics also show in the models how asymmetries arise in “real” supernovae. Previous simulations in two dimensions revealed that the spherical shell structure of the predecessor star is destroyed in the supernova explosion, and that mixing takes place on a large scale. The details, however, remained hidden. Supernova 1987A, probably the most examined stellar catastrophe, served as a test case. In future simulations, the researchers will examine a broader range of predecessor stars and initial conditions. They also want to formulate a model that explains all the characteristics of SN 1987A and find out how the stellar explosion begins and what triggers it. (Astrophysical Journal, May 10, 2010)

Nitrogen Binds Greenhouse Gas

Nitrogen in the soil reduces the greenhouse effect – and not only as a fertilizer that plants use as an aid to binding carbon dioxide from the atmosphere. At least in the forests of the temperate latitudes, fertilizer also slows the breakdown of organic material in the soil, so that less carbon dioxide is released from the Earth into the atmosphere. This is the conclusion reached by an international team of researchers including scientists from the Max Planck Institute for Biogeochemistry in Jena. The researchers compiled data from a number of different field studies and laboratory experiments. According to this data, the microorganisms in most soils release less carbon dioxide with a moderate discharge of nitrogen, partly because the abundance of nitrogen changes the microbial environment and the microorganisms are saved the effort of consuming woody plant waste that is hard to digest. On average, carbon dioxide emissions from the soil fall by 10 percent. This means that the effect is roughly as significant as that of increasing plant growth. The researchers warn that this effect is nevertheless being neglected in current models of the carbon cycle. (Nature Geoscience, May 2010)
First-Generation Cosmic Power Stations

Astronomers are finding primitive quasars with the Spitzer space telescope

Previously, they existed only in astronomers’ models: primitive black holes that populate the cores of active galaxies and that were already present in the young universe. Researchers have now discovered not one, but two of these gravitational monsters. They are revealed to be quasars, and their light originates from a time when the universe was barely a billion years old – we are seeing them as they were 12.7 billion years ago. A quasar is the central region of a galaxy that contains an active black hole. This lies in a brightly shining disk which itself is surrounded by a huge ring of dust.

Using the Spitzer space telescope, astronomers from the Max Planck Institutes for Astronomy in Heidelberg and for Extraterrestrial Physics in Garching have now observed 20 quasars in infrared light. In this spectral range, it is possible to identify the characteristic radiation from hot dust, a typical component of modern quasars. On examination, however, two of the quasars showed no signs of hot dust. This means that they must be early primitive examples, as there was no dust in the early universe. Furthermore, the researchers found that, in the most distant quasars, there was a correlation between the mass of the black hole and the dust content: the greater the mass of the central black hole, the more dust the quasar contains. This indicates a development process in which the black hole grows rapidly by swallowing up matter while, at the same time, more and more hot dust is produced. (Nature, March 18, 2010)

An infrared eye: Astronomers have now discovered the most primitive black holes in the universe with the Spitzer space telescope.

Human Stem Cells Remain Indispensable

The mouse is one of the most important model organisms in stem cell research. Scientists in Germany are permitted to use human embryonic stem cells for research only when they have previously examined animal cells. However, such tests are frequently of no use because, despite all the similarities, findings from examinations of the embryonic stem cells of mice cannot simply be applied to humans. A current study by researchers working with Hans Schöler from the Max Planck Institute for Molecular Biomedicine in Münster shows that epiblast stem cells from mice react differently than human embryonic stem cells to the growth factor FGF. While FGF actively supports renewal of human cells, this is not the case in the mouse epiblast cells. “This means that many preliminary investigations using animal cells, particularly projects relevant to medicine, might not only be of no use, but the results of such advance tests can even be misleading,” warns Hans Schöler. Human cells will therefore remain essential for stem cell research in the future. (Cell Stem Cell, March 5, 2010)

The illustration shows nerve cells (green) from the epiblast stem cells of a mouse. They are created four days after FGF and other growth factors have been blocked. It is also possible to create nerve cells from human stem cells in this way.

An infrared eye: Astronomers have now discovered the most primitive black holes in the universe with the Spitzer space telescope.
Are Winters Becoming Colder in Europe?

Low solar activity could affect the regional climate in Great Britain and Central Europe

Despite the trend toward global warming, people in Great Britain and Central Europe might experience cold winters more frequently over the next few years. This is the conclusion drawn from a study by scientists from the University of Reading, the Rutherford Appleton Laboratory in Oxfordshire in the UK, and the Max Planck Institute for Solar System Research in Katlenburg-Lindau. The researchers examined British weather records going back to 1659 and compared them with solar activity over the same period. The strength of the solar magnetic field was used as a measure of the Sun’s activity. As sufficiently reliable data is available only for the years after 1900, the researchers reconstructed older values with computer simulations. The statistical comparison of the magnetic “fever curve” of the Sun with the weather database paints a very clear picture: after decades of high solar activity and comparatively mild winters, cold winters are becoming more frequent in Europe.

When there is low solar activity, the average winter temperature in the UK is around half a degree lower than usual. The reason for this very regional effect of low solar activity could be attributed to wind changes in the troposphere, the lowest layer of our atmosphere. If the stratosphere that lies over it heats up only slightly, the mild strong winds from the Atlantic are blocked. Instead, the UK and Central Europe are exposed to the effects of cold winds from the northeast. The exact mechanism for this is, however, still unclear. (Environmental Research Letters, April 15, 2010)

Firm Footing for Mussels

Mussels have an iron grip on stones and rocks – and that’s not just figuratively speaking. The byssus, the threads with which mussels hold fast to the ground, hardly ever wears out, although waves constantly pull at it and it is abraded again and again by stones. Scientists at the Max Planck Institute of Colloids and Interfaces in Potsdam-Golm have found that the fibers owe this resistance to iron atoms in their cuticle, over which the proteins in the mussel form a network. Bonds form on the iron atoms, which, in some cases, break under stress so that the material can stretch further. These fractures then close again. This means that nature achieves what materials scientists hardly ever succeed in: making a material stretchable and hard at the same time. The researchers are hoping that nature’s principle can be used to make technological materials with similar properties.

Secured for life in a strong current: Mussel shells hold onto rocks with byssus threads. Strengthened by iron, the fibers are resistant to abrasion.
The Call of the Horseshoe Bat

Bats recognize the calls of other bat species

The echo location calls of bats hold more information than was previously thought. Not only can bats distinguish their calls from the calls of other species, but they can also recognize the different calls made by other species – similar to the way in which we humans differentiate between different languages. Maike Schuchmann and Björn Siemers from the Max Planck Institute for Ornithology in Seewiesen played echo location calls produced by their own species and by three other species through a loudspeaker to two species of horseshoe bat, and analyzed their reactions. Both bat species made almost no mistakes when distinguishing between their own and the other species, or between different calls by the other species. The scientists now want to move on to finding out how bats use this capability. The animals might profit from this, for example, when they stay out of the way of the hunting area of a stronger competitor. It would also be of benefit to follow other species with similar habitat requirements when they are searching for new places to roost. (The American Naturalist, May 11, 2010)

The Meheley horseshoe bat (Rhinolophus mehelyi) can even identify closely related species from their calls.

Squeezing Quantum Noise

Compact and seemingly more precise than quantum physics permits – this is how the atomic clock of the future might tick. A team working with physicists from the Max Planck Institute of Quantum Optics and Ludwig Maximilian University in Munich has contrived a way to improve the accuracy of measuring instruments that work with quantum particles on a microchip. Moreover, it goes beyond the quantum limit. This limit exists because the behavior of quantum particles is subject to probability. The quantum noise that results manifests itself when a measuring point becomes a patch, for example. The researchers have now squeezed this round measuring patch into a cigar-shaped structure, which increased the accuracy in one direction, but at the price of lowering the accuracy in the other direction. They achieved this by trapping rubidium atoms on a microchip. The behavior of one atom determines what happens to the partners trapped with it. Unlike other attempts at calming, they also save energy in this way – five times as much as they need to trigger the turbulence. (Science, March 19, 2010)

Bringing Turbulence Under Control

A method of controlling turbulent flows is helping to save energy. Whether it is oil or water being pumped through a pipe, turbulence often consumes ten times as much energy as a calm flow traveling at the same speed. Scientists at the Max Planck Institute for Dynamics and Self-Organization in Göttingen and at Harvard University in the US have found a way to calm relatively slow-moving turbulence in a glass tube. Using simulations, they found that they can halt turbulence by changing the speed profile of the flow behind it. They slow the flow in the middle of the tube and speed it up on the edge by deliberately creating turbulence in the middle of the flow. Unlike other attempts at calming, they also save energy in this way – five times as much as they need to trigger the turbulence. (Science, March 19, 2010)
Many aspects of quantum physics are mystifying and puzzling: particles can be in two places at once and combine characteristics that are mutually exclusive. Ignacio Cirac, Director at the Max Planck Institute of Quantum Optics in Garching, is developing ideas for using these mysterious quantum phenomena to process information.

A theory for difficult cases of magnetism: Colleagues of Ignacio Cirac calculate how the magnetic moments of electrons (spins) interact when the north and south poles of these tiny magnets can't always dodge each other. The height of the peaks indicates the intensity of the interaction. They deduce the magnetic order from the symmetry of the graph.
The yellow leather chairs in Ignacio Cirac’s office still exude a hint of Spanish sun even when the sky outside is heavily hung with dark clouds and rain dampens the summer atmosphere. Here at the Max Planck Institute of Quantum Optics on the Garching research campus, the Spanish-born theorist contemplates the problems of quantum physics.

“Right from the start, quantum mechanics has had a puzzling side,” says the 44-year-old institute director and physics professor, describing the situation: “Scientists such as Einstein, Bohr and others considered this aspect like a curious game, like something that isn’t actually true at all.” In recent years, physicists are giving more thought to the practical aspects of this mysterious side of quantum physics, and modern technology even allows them to conduct related experiments. “In this way, we can now put these mysteries to the test, all these strange effects of nature,” says Cirac.

For the average citizen with any common sense, what happens in the quantum world – the world of the very small – sounds more like a fairy-tale anyway: particles that transform into waves and vice versa; particles whose location and speed can’t be measured simultaneously; energy that occurs only in packets. Physicists call these phenomena duality, uncertainty relation and quantization.

PARTICLES SEEM TO COMMUNICATE TELEPATHICALLY

They are not fairytales, but the foundations of our modern world. Without these astonishing phenomena, there would be no computers, no lasers, and no magnetic resonance imaging today – there would not even be an ordinary television. The things that seem so inexplicable and puzzling to those with common sense have since been proven in practice a million times over.

But there is a part of quantum mechanics that still remains a mystery: Particles that seemingly communicate by telepathy. Hypothetical cats that are simultaneously dead and alive (see box “A Cat in a Box”). Cold matter that behaves contrary to all known laws of nature. There are scientific names for these phenomena, too, but thus far they have remained pure descriptions: entanglement, superposition of states, superconductivity, superfluidity. While some of the rules of these phenomena are known, in many cases, it is not known how they come about and on which theory they are based.

A good 15 years ago, some researchers changed their perspective and considered the secrets as challenges. Cirac is one of them. “So we said: There is a nature that behaves very strangely. This is not only a challenge. Cirac is one of them. “So we said: There is a nature that behaves very strangely. This is not only a challenge. Cirac is one of them. “So we said: There is a nature that behaves very strangely. This is not only a challenge. Cirac is one of them. “So we said: There is a nature that behaves very strangely. This is not only a challenge. Cirac is one of them.
closely with Cirac. “There, my Austrian colleague Peter Zoller, Ignacio Cirac and I met British physicist Arthur Ekert, who presented the idea that, in a quantum computer, as in a conventional computer, one needs a set of fundamental gates that can execute certain logical decisions.” As soon as they were available, any computing operation could be done by a sequence of these fundamental gates. Zoller and Cirac took up this idea and, within a few weeks, wrote down how it could be realized.

Unlike a conventional computer, a quantum computer works with the superposition of various states, so-called qubits (see box “Quanta You Can Count On”). These offer the advantage of allowing many calculations in parallel in a single step, since all states are calculated simultaneously. However, each measurement means intervening in the system and destroys the superposition. Physicist Erwin Schrödinger illustrated this phenomenon in 1935 with his image of the cat that is simultaneously dead and alive. But how can logical operations be linked without measuring the state of the qubits and thus destroying them? In 1994, Cirac and Zoller came up with the idea how one can entangle the state of a qubit with a movement and thus be able to entangle qubits without measuring them.

**QUANTA YOU CAN COUNT ON**

It is well known that digital information is composed of bits. In a conventional computer, a bit can take on the value 0 or 1, which is represented by the charge state of an electronic device. There are states in quantum mechanics as well, corresponding to 0 or 1, such as the excitation state of an atom or the direction of rotation of a rotating particle, called the spin. An excited atom, for example, could stand for 1, and one in the ground state for 0. Bits in the quantum world have come to be known as qubits.

Quantum mechanical objects, however, are not always in an unambiguous state, but can appear to be in a superposition of all possible states simultaneously. Thus, a qubit can simultaneously encode 0 and 1. So two qubits take on the four states 00, 01, 10 and 11 – simultaneously. The number of possible combinations increases rapidly: 32 qubits already yield four billion. This variety is to be put to use in a quantum computer: each computing operation would then take place in all states simultaneously. With two qubits, four values are automatically calculated simultaneously, and with 32 qubits, four billion values.

However, the superposition of the states collapses as soon as the system is disrupted. At the moment of measurement, physicists describe reality precisely: only a single state remains, namely the measured value.
The entanglement of two objects is a phenomenon that Albert Einstein had already referred to as “spooky action at a distance” and that exists only in the quantum world: two entangled quantum objects are always in the same state – no matter how far apart they are. Translated into quantum gates, this means that, if one of the qubits is excited, it causes a movement, and if it is not excited, it doesn’t. Observing the movement does not destroy the superposition in the qubits.

In 2001, David Wineland’s group in Colorado realized a quantum gate, implementing the ideas of Cirac and Zoller for the first time in an experiment. Shortly thereafter, Rainer Blatt in Innsbruck succeeded with this, too. His team used ion traps to build a quantum gate. For this, the physicists use suitable electromagnetic fields to trap charged atoms in a small vacuum chamber and manipulate them with lasers, thus entangling their states with movements. This method is now established practice, and entanglement can be created practically at the touch of a button using the Cirac-Zoller method – a process that previously seemed unthinkably.

Before this, one could find only particles that were entangled naturally. “In a non-linear optical crystal, two entangled photons can be generated, for example, by the incidence of a high-energy quantum,” explains Ignacio Cirac. But how can three entangled photons be produced, or 30, as would be needed for a quantum computer?

He and his colleagues thus proposed a way to intentionally entangle ions. “Today, we can say: Tell me what state your particles are in and we’ll give you a procedure for entangling as many of them as you want,” says Cirac.

**Computations – Led out of isolation**

Experimental physicists have a choice of many theoretical proposals for experiments. However, since Ignacio Cirac enjoys an outstanding reputation among experts, he and his group of 30 theorists also always successfully gain partners for experiments for current projects. In this way, in July 2009, Cirac and two former colleagues proposed a new theory that questions a further principle of the quantum world. Several teams are now working on proving it experimentally.

It was previously believed that the qubits in a quantum computer had to remain free of disturbances from external actions in order to keep their superposition intact. That is why the system must be completely isolated from the outside world, making interim measurements impossible. Researchers call this undesired contact with the environment dissipation. Only when the calculation is complete do the experimenters

To entangle the state of an atom with a movement, Ignacio Cirac and Peter Zoller proposed the following method: Arrange several ions in an ion trap in the form of a chain and bring them into a state of absolute motionlessness. This is easier said than done. To achieve this, several cooling methods must be combined, including laser cooling and sideband cooling. The ion chain constitutes a harmonic oscillator, which possesses internal quantum states. When it is in the absolute ground state, the chain is absolutely motionless, although Coulomb interaction is still present between the ions.

When this absolute ground state is reached, an ion can be brought into an excited state by manipulating it with a suitable laser impulse. If this is done the right way, one can use quantum logic means to ensure that a movement occurs between the ions in the trap due to Coulomb interaction. In this way, there is not only a transition between excitation states, but also a kick that causes the ion to move. The movement is very small – just a few nanometers. But it means that the entire chain now begins to oscillate.

In principle, the system doesn’t even know which ion generated the movement. This not knowing is also a kind of superposition. So one can say that the internal state has been entangled with the external movement of the ions. The optical transition was converted into a movement state.
read out the result, by taking a measurement – and destroying the superposition. "But now we have found that one can observe the system and still make quantum calculations," says Cirac: "This proposal contradicts all previous concepts of a quantum computer."

However, the researchers must make the observation in a very specific way. Then, although the superpositions will collapse, they will do so in a way that leads to the problem’s solution. How this might look in practice is still not clear. In any case, in 2009, the European Union set up a three-year research project called Quevadis to promote relevant experiments. “Ultimately, there are two basic types of quantum computers,” Cirac sums up. “The one requires complete isolation, the other, full dissipation.” In the end, perhaps it will be possible to combine the advantages of both types.

SIMULATORS FOR QUANTUM SYSTEMS

And there is yet another project that Ignacio Cirac is pursuing: He is helping to realize an idea that the legendary physicist and Nobel laureate Richard Feynman touched on as far back as 1981. Feynman doubted that the world could be described precisely with a conventional computer: “I am not happy with all the analyses that go with just classical theory, because nature is not classic, dammit. And if you want to make a simulation of nature you’d better make it quantum mechanical and by golly it is a wonderful problem.” Now, research groups around the world are working on this “wonderful problem” – among them the theoreticians at the Max Planck Institute of Quantum Optics: they want to simulate quantum systems.

THE MICRO COSM IS BECOMING PREDICTABLE

Cirac explains the basic principle using the classical simulations that are common today: “Let’s say you want to design an aircraft and see whether it can fly before you build it. You simulate all the major components on the computer, and with suitable equations, you can make a prediction.” Computers can simulate a lot of things this way. “But no conventional computer can simulate the quantum systems in our microscopic world,” says the physicist.

The behavior of atoms at very low temperatures, for instance: Will they conduct electricity or not, will they display superconductivity? Conventional computers fail here – this calls for quanta. It need not be an actual quantum computer – a simpler quantum system is sufficient as long as it can be controlled to such an extent that, at low temperatures, it behaves like a group of atoms. Then it can be used to make predictions about the unknown system (see MaxPlanckResearch, 1/2009, page 32 ff.).

Currently, the focus is on the question of why some materials exhibit superconductivity even at relatively high temperatures – that is, why they conduct electricity without resistance at relatively high temperatures. “We hope our quantum simulators will help us find out why high-temperature superconductivity exists,” says Cirac. As soon as the mechanism is clear, it may be possible to systematically build such materials to conduct electricity loss-free at temperatures that also facilitate broad application.

There are still adventures and surprises in physics, even in theory. Ignacio Cirac is very satisfied with this situation. “I always tell people who don’t do research themselves: Imagine that you go on a journey and you discover a stone that no one has ever seen before. It feels great. And we get this feeling every day.”

GLOSSARY

Superposition
Particles don’t take on one state, but rather all possible states at once – until a measurement destroys the superposition.

Entanglement
Two or more particles form a joint system, and measuring one particle instantaneously affects its entangled partners – regardless of how far apart the particles are from one another.

Superconductivity
Below the so-called transition temperature, which is usually below minus 260 degrees Celsius, many metals conduct electricity without resistance. Physicists understand this conventional form of superconductivity very well, but this is not yet true for the unconventional form of superconductivity. It occurs, for example, in copper-oxide ceramics, where the record holder loses its electrical resistance at a mere minus 110 degrees Celsius.

Superfluidity
This phenomenon was first observed with two isotopes of helium. Due to quantum mechanical effects, a liquid or a gas flows without friction.
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We foster technical journalism. The „Vogel Foundation Dr. Eckernkamp“ has been funding an endowed professorship at the Würzburg-Schweinfurt University of Applied Sciences since 2008. The Masters Degree course in Technical Journalism, which is the only one of its kind in Southern Germany, provides a well-rounded, multi-media centric education, strengthening the knowledge base in Germany.
Meet the Neanderthals

Well, they actually did it. And the whole world knows about it now, even if the news is tens of thousands of years old. It was, of course, a juicy story for the world’s media: Neanderthals mated with modern humans! But for Svante Pääbo, Department Director at the Max Planck Institute for Evolutionary Anthropology in Leipzig, this is not the most important aspect of his discovery.

Svante Pääbo relaxes in a chair in his office. “Many people think the interbreeding of humans and Neanderthals is really cool,” he says. He doesn’t deny that he thinks so too, but maintains: “In the long run, it is much more important that we now have a genome from the closest relative of all present-day humans.” Standing behind him is a life-size model of a Neanderthal skeleton.

Pääbo has every reason to relax: He has completed in five years a project that others in the past could only dream of. For the first time ever, scien-
Face to face: Svante Pääbo holds the skull of one of our closest relatives, the Neanderthal.
Neanderthal mtDNA was so different from the mtDNA of people today that it was unlikely that Neanderthals had mixed with modern humans.

tists have the genome of an extinct member of the genus Homo. The Neanderthals died out some 30,000 years ago. Now that we have their genome sequence, we can delve a little deeper – and not only to find out who or what the Neanderthals were: “Above all, we can describe what changes have occurred in our genome, and some of those must have contributed to making us unique,” says Pääbo. This is a point he makes again and again in every interview. It’s not primarily about the Neanderthals, it’s about us.

SPOTLIGHT ON PALEOGENETICS

The publication of the Neanderthal genome in the journal Science on May 7, 2010 is a high point in the career of the 55-year-old, the son of Nobel laureate and biochemist Sune Bergström. It is also a highlight for his colleagues and the entire research field of paleogenetics, an area in which he played a pioneering role in the 1980s. Pääbo, who studied Egyptology and then medicine, earning a doctorate in immunology, had yet another research interest: he wanted to decode the DNA of mummies. Nobody had ever done that before. Scientists were not even sure that DNA could be extracted from mummies.

Unbeknownst to his dissertation supervisor, he worked nights on the project. “I was a bit afraid of him, as he might have stopped me from doing it,” recalls Pääbo. When he actually found the DNA in microscopic sections of mummies and was able to stain it and even extract it, he was ecstatic. “Then I had to tell my supervisor,” he remembers with an ironic smile. He submitted his results to Nature and even ended up on the cover of the journal in 1985. It was the perfect start to a career in science.

Following a period in Berkeley, Pääbo was given his own lab at Ludwig Maximilian University in Munich in 1990. It was there, during the mid-1990s, that he studied the DNA of Neanderthals for the first time and found the initial evidence that the “big oaf” was not a direct ancestor of humans. His group had extracted DNA from the mitochondria, the “powerhouses” of the cells. Because many mitochondria are present in each cell, they yield more DNA than the cell nucleus – mitochondrial DNA (mtDNA) can thus be analyzed more easily than nuclear DNA.

Neanderthal mtDNA was so different from human mtDNA that it was unlikely that Neanderthals and Homo sapiens had mixed to any large extent.

In 1997, Svante Pääbo moved to Leipzig as one of the five Directors of the new Max Planck Institute for Evolutionary Anthropology in the city. At that time, the focus of the international research community was on sequencing the human genome. The publicly funded human genome project began in the US in 1990 and faced competition from American geneticist Craig Venter’s privately owned biotech company, Celera Genomics, which launched a similar project in 1998. The competitive aspect helped to accelerate the research work. In 2001, both the public and private research efforts were in a position to present a draft version of the human genome. At this stage, nobody even dreamed of reconstructing the entire Neanderthal genome.

Compared to the sequencing of the DNA of living individuals, a whole series of obstacles must be overcome before “old DNA” can be decoded. One of the main problems is that a sample from a 10,000-year-old Neanderthal bone may contain a lot of genetic material, but more than 95 percent of it does not belong to our caveman.

“This is DNA from bacteria or fungi that have colonized the bone after death,” explains Pääbo.

LETTERS SWITCHED IN THE NEANDERTHAL SEQUENCE

The second problem is that, over time, the DNA strand disintegrates into smaller and smaller fragments, like a jigsaw puzzle whose pieces are scattered in the box. Some parts are still connected, but the overall picture (the sequence) is unrecognizable. The problem is compounded by the fact that some of the building blocks are chemically modified. Pääbo and his team discovered that one of the four bases in the genetic code changes its identity over time. Instead of a C for cytosine, many of the sequence fragments contain a U for uracil, especially at the ends of the fragments, where the cytosines lose their amino groups easily.

During sequencing, the U is read as a T for thymine. “So when we find a T in the first position of a sequence, in 40 percent of cases, it is actually a C,” explains Pääbo.
Tomislav Maricic examines the bone fragment of a Neanderthal in the clean room.

The researchers must take extensive precautions before they can enter the clean room.

Only 400 milligrams of bone powder is actually needed for the analysis; the researchers extract this from the bone fragment.
A critical problem is caused by the researchers themselves: they can contaminate the samples with their own DNA. Individuals may leave small amounts of DNA behind, whether during the excavation at the archeological site or when preparing the gene fragment in the lab. This is helpful at the scene of a crime, but it can ruin the work of the paleogeneticists.

Pääbo and his team had to overcome all of these obstacles one by one. For example, the researchers succeeded in increasing the yield of Neanderthal DNA by a factor of 300. This was an important achievement as, before these advances, it looked as if the sequencing would take another two decades and cost 60 million euros.

A PAINSTAKING PROCESS WITH OLD DNA

The researchers enrich the Neanderthal DNA by using, for instance, molecular scissors that cut the microbial rather than the human genetic material. “In this way, we enrich the samples by up to 20 percent, which makes the sequencing affordable,” says Pääbo. To counteract the changed identity of the cytosine, the researchers wrote bioinformatics programs with which they corrected their computer algorithms for the sequencing to factor in the probability that a T was actually a C. “In a fragment that is 50 base pairs in length, this allows us to decide with confidence whether the DNA is from a Neanderthal or from a bacterium,” explains Pääbo.

Contamination by the researchers’ own DNA was a problem that the group had to grapple with for a long time. Numerous precautions were taken. This involves handling the samples in a clean room, similar to the type used in the chip industry. The air is constantly filtered and the scientists work in protective clothing. When the room is not in use, UV light destroys any remaining DNA. Yet all of these precautions were not sufficient for an experiment that the team carried out in 2006, details of which were published in Nature. “Given that we had taken these precautions, we thought that we had only 1 percent contamination. In fact, the figure was perhaps 14 percent,” says Pääbo. What happened?

A NEW GENERATION OF SEQUENCING MACHINES

The Leipzig team had sent their samples to the US-based manufacturer of the latest generation of high-throughput sequencing machines. However, the manufacturer did not have a clean room there. “We knew that that could be problematic, but we wanted to test the new machines before investing in them,” explains the Max Planck Director. And that is where the foreign DNA is likely to have contaminated the samples. “It was annoying, but in retrospect it was a good thing, as it meant that we discovered a problem that we had to solve. This is how progress is made in science – we can’t get perfect results right away.”
In the meantime, the sequencing machines are in Leipzig and each fragment of Neanderthal sequence is marked with a tag of four bases, clearly distinguishing it from contaminating human DNA, which is unmarked. And one improvement followed another. The new generation of high-throughput sequencing machines from the US company 454 Life Science was a technological quantum leap. It really put the reconstruction of the sequence of three billion base pairs within reach: “That was when I realized that we were going to make it,” says Svante Pääbo.

In late March, Krause published details in *Nature* of an exciting discovery in a cave in the Altai Mountains in southern Siberia. They had results that showed that a previously unknown hominin lived there around 40,000 years ago. If the Max Planck researchers’ claims prove to be true, it would be the first time a paleontological human form has been discovered solely through DNA analysis. The DNA sample came from a sliver of finger bone, no bigger than a cherry pit. It was found in 2008 by the Russian researchers from Novosibirsk with whom Pääbo’s lab have been collaborating for a number of years.

Johannes Krause sequenced its mtDNA. The advantage of this method is that, with approximately 16,000 base pairs, the sequence is very short and there are several hundred copies in each cell. When Krause examined the preliminary sequencing results, he couldn’t believe his eyes. “It was a very exciting moment. Something wasn’t quite right,” says the 29-year-old. A discovery or an artifact? He was suspicious. Had something gone wrong with the analysis? Had an error occurred in the complex bioinformatics programs and algorithms the paleogeneticist was using to reconstruct the gene fragment?

Several control experiments, however, confirmed the unexpected result. Krause sequenced each position of the sequence more than 150 times. “I even called a meeting with my colleagues at 6:30 on a Friday evening to discuss the results with them,” says the scientist. But his colleagues were also unable to explain the phenomenon: this sequence did not come from a modern human or a Neanderthal, but from an unknown third type of human.

The difference is clear: while the Neanderthal mtDNA differs from human mtDNA at an average of 202 positions, and from chimpanzee mtDNA at more than 1,400 positions, the genetic material in the finger bone found in the southern Siberian Denisova Cave differed at 385 positions. Using the mutation rate, the molecular clock, Krause determined that, roughly one million years ago, this hominin’s line diverged from the line that subsequently gave rise to Neanderthals and modern humans.

The discovery is exciting also because it adds a new slant to the picture we have of hominin evolution. Modern humans seem to have shared the Earth with other human species for tens of thousands of years. All of these other hominin groups became extinct, while modern humans conquered the world. The discovery of the “hobbit,” the small Homo floresiensis on the Indonesian island of Flores, is another example of this.

But before the Leipzig-based Max Planck researchers commit themselves definitively, they want to first sequence and analyze the nuclear DNA. “New information is emerging all the time, some of which calls previous results into question. It is all much more complex than we initially thought,” says Johannes Krause. Was there perhaps even some interbreeding, as in the case of the Neanderthals? He hopes to have a conclusive answer to this question by the end of the year.

And once again, a technical advancement led the way for a scientific breakthrough.

**THE THIRD (WO)MAN**

Just a few weeks before the Leipzig-based lab made headlines around the world with its revelations about the Neanderthal genome, Svante Pääbo and his colleague Johannes Krause were already dealing with a surge of media interest. In late March, Krause published details in *Nature* of an exciting discovery in a cave in the Altai Mountains in southern Siberia. They had results that showed that a previously unknown hominin lived there around 40,000 years ago.

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ly impossible using the type of machine available in 2004.” According to Briggs’ calculations, “It would have taken one of those machines 10,000 years, or 10,000 machines one year, to do this – and at a cost of several hundred thousand dollars, it would have been impossible to finance.”

**DATA ANALYSIS TOOK ALMOST ONE YEAR**

The difference between the old and new generation of these otherwise nondescript boxes is perhaps best illustrated by a look at the palm-sized plates that contain wells in which the DNA fragments are sequenced: on the old machines, there were 96 indentations per plate; in the 454 Life Science machine, there are 1.6 million. “This means that we can sequence more than a million DNA fragments per plate, compared to the 96 per plate with the older model,” says Briggs.

Thanks to an additional cash injection from the President’s Strategic Innovation fund, the researchers were able to afford this state-of-the-art sequencing technology. “It has to be said that people in the Max Planck Society recognized the potential and provided the necessary resources,” says Pääbo.

The time, money and hard work paid off. In February 2009, the team announced that it had achieved its objective, but this was all that was made public; the sequence wasn’t published as there was still more work to be done. “We had the feeling that we had to tell the world we had done it, as we had questions from journalists all the time,” says Pääbo. It took just under a year to perform the analysis of the data.

The results are impressive – a real milestone in the study of human evolution. Pääbo and his colleagues sequenced four billion base pairs, from which they were able to reconstruct more than 60 percent of the Neanderthal sequence by comparing their data with the human genome and the chimpanzee genome.

“We were able to sequence some of the positions in the sequence several times, and others we were not able to sequence at all,” says Johannes Krause, who has been working in Pääbo’s lab since 2005. To perform the analysis, the Leipzig researchers organized a consortium of groups, mainly in the US, involving more than 50 individuals.

It came as a surprise that there was a small amount of interbreeding between Neanderthals and humans – and the news made headlines around the globe. Between one and four percent of human DNA in people living outside Africa originates from Neanderthals. The researchers were even more surprised by the fact that our burly Ice Age ancestors left their genetic traces not only in Europe, but also in China and Papua New Guinea. “That was something we didn’t expect,” says Pääbo. Until now, there has been no proof whatsoever that Neanderthals ever lived in these regions. It follows, therefore, that there must have been sexual contact before early modern humans expanded into Eurasia from Africa.

The simplest explanation would be that there was an encounter between the two groups in the Middle East. Paleontological evidence proves that the two groups lived in the same region between 80,000 and 50,000 years ago. However, the possibility that the
Mitochondria
Cell organelles surrounded by a double membrane that contain their own genetic material (mtDNA) whose role is to provide the cell with energy in the form of ATP. New mitochondria are only formed in a process similar to binary fission. They are believed to have originated at an early stage of evolution, by eukaryotic cells (cells containing a nucleus) absorbing bacteria and changing their function (endosymbiosis).

Nucleotides
Nucleotides are the basic building blocks of DNA and RNA. They consist of a phosphate unit, a sugar module and one of the five nucleobases, Adenine (A), Guanine (G), Cytosine (C), Thymine (T) or Uracil (U). The latter are the letters of the genetic code and form the DNA sequence.

High-throughput sequencing
This technology is used to determine the sequence of letters from genetic fragments within a very short time. This leads to a huge increase in the generation of sequencing data and reductions in cost. In the foreseeable future, it will be possible to sequence entire genomes for a few thousand euros.
Instead of taking center stage as the prima ballerina she once wanted to be, Nicole Dubilier has become a star of the international science arena. The renowned scientist researches deep-sea bacteria and worms at the Max Planck Institute for Marine Microbiology in Bremen.

TEXT KLAUS WILHELM

What a laugh! Over and over again, Nicole Dubilier erupts into peals of deep, hearty, contagious, spirited, congenial and loud laughter. She simply can’t help it, it seems. Even if – or more precisely, when – she is talking about the things that mean the world to her: science, family and the ocean.

The joyful, downright exuberant biologist from the Max Planck Institute for Marine Microbiology adopts an equally upbeat tone when recounting tales about her excursions in the Atlantic and Pacific Oceans with the research ships Meteor, Sonne, and Maria S. Merian, when explaining symbiosis – that tightly knit “marriage of convenience” between various living organisms – or the new world of molecular biology that is gradually unveiling the secrets that lie behind the phenomenon of symbiosis, or when simply talking about bacteria and worms. Yes, worms! Spontaneity and candor come just as easily to this down-to-earth woman as laughter – and research. She likes stories and life in general – and her own life. All this is immediately obvious upon meeting her.

Nicole Dubilier is sitting in her modest office on the first floor of her institute in Bremen. Pinned to the notice board is a card with birthday greetings from the crew of the Maria S. Merian, and a humorous “baptismal certificate” for crossing the equator on the high seas from the crew of the Meteor. The sparse office contains just a few desks and shelves lined with specialist books and publications. The window overlooks the institute garden and pond, and Bremen’s Bürgerpark forest is visible in the distance – it is easy to see how the view could provide a source of inspiration. “Nicole von Wurm,” as the ironic, yet highly symbolic nameplate on her office door reads, has been leading the now twelve-strong “Symbiosis” Research Group from this office since 2007.

**MENAGE À TROIS BETWEEN A WORM AND TWO BACTERIA**

The livewire from the coast – Nicole Dubilier has been living in Hamburg since the 1970s – has had a formative influence on this research field over the past decade. She was responsible for the discovery of a new form of symbiosis: a symbiotic menage à trois between a
Letting her hands do the talking: When Nicole Dubilier addresses students in the seminar room, she does not rely on speech and humor alone. Her animated facial expressions and vivid hand gestures also help her get her message across.
On three different occasions, Dubilier was tempted to throw in the towel, but each time she gritted her teeth and carried on. After a long six-year struggle, the determined and strong-willed woman finally received her doctorate.
The microtome is a device for cutting extremely thin sections of material embedded in a block of wax. Nicole Dubilier rarely finds the time to tinker with the microtome. Well nourished despite the lack of a digestive tract: Olavius algarvensis, an oligochaete and relative of the earthworm, might not have a mouth or digestive system, but that does not mean it has to starve. The organism, which is only about two centimeters long, has bacterial endosymbionts to thank for this.
Dialogue in the institute’s Lander workshop: Nicole Dubilier discusses improvements to the equipment with the sea technician, Marc Viehweger.

Laughter is an essential part of the process: Nicole Dubilier clearly enjoys her work.

Looking back at the last sea voyage: Nicole Dubilier discusses a map with a hydrothermal vent field on the Mid-Atlantic Ridge with some members of her team – (from left) Caroline Verna, Karina van der Heijden, Silke Wetzel and Dennis Fink.
Dubilier was tempted to throw in the towel, but each time she gritted her teeth and carried on.

After a long, six-year struggle, the determined and strong-willed woman finally received her doctorate in 1992. It was clear to her, however, that she would not be able to survive many more years like this, as “it is frustrating when you work hard and remain unfulfilled.” The plan: “I’ll give myself one more year as a post-doc,” working on a different topic, doing a different kind of research. She would soon know if it really gratified her: it would have to feel like ballet.

It turned out to be molecular biology, or more specifically, the symbiosis between worms and bacteria, that provided the satisfaction she sought. Molecular biology provided the right path because, in a way, it is less tedious than physiology. “When it works, that’s it. You don’t have to repeat the experiment five times,” says the researcher. What fascinated her about symbiosis was the idea of cooperation; the fact that evolution is not driven solely by egoism and competition, and that cooperation and reciprocity can also be the engine of evolution. In this life form, each participant contributes something that helps the other participant. “That touched me,” she says. “So much so that it grieved me when some symbionts “cheated” on their partners.”

This could be interpreted as a typically female perspective on things: cooperation instead of egoism. However, Nicole Dubilier counters such an interpretation with hard facts and the conviction of an inspired researcher. She goes on to explain how symbiosis is an ancient process: without symbiosis, life would not have been able to develop on Earth. The symbiosis between bacteria and primitive protozoa, in particular, fueled the spread and evolution of plant and animal cells, and shaped the development of life on Earth.

Today, almost all plant, animal and human cells, with their minute energy power plants, the mitochondria, still contain the descendents of earlier bacterial symbionts – without mitochondria, we would not be able to breathe. Dubilier explains that innumerable bacteria thrive in the human bowels and return the favor by supporting digestion, or possibly even strengthening the immune system. Symbioses can be found wherever you look.

It may thus come as some surprise to learn that symbiosis only gradually took off as a research field in the mid-1990s. To enable scientists to find out more about the emergence of these partnerships, as simple a model as possible was needed. Olav Giere’s gutless shallow-water Bermuda worms appeared tailored to this task. With the worm cultures in her suitcase, Nicole Dubilier headed off to Harvard University, to Colleen Cavanaugh’s laboratory, which had made a crucial contribution to the discovery of the deep-sea tubeworms with their bacterial symbionts. It was in this prestigious setting that Nicole Dubilier became familiar with the tools of molecular technology.

CREATIVITY IN HER BLOOD

The move to Harvard also marked a return to her native country: Nicole Dubilier is American by birth, with an interesting and eventful biography. Her original nationality is not immediately obvious to anyone who hears her chat in perfect Hanseatic German. However, a slight American accent creeps into her energetic Hamburg German at times.

She was born in New York and grew up on the Upper East Side, one of the Big Apple’s most illustrious neighborhoods. There’s no doubt about it: the eldest of four children, Nicole Dubilier comes from a distinguished background. Her father was an American businessman and her mother a descendant of the renowned Berlinphysiologist Emil du Bois-Reymond and Fanny Mendelssohn, sister of the composer Felix Mendelssohn-Bartholdy. Creativity is clearly in her blood.

Her German mother emigrated to the US in the 1950s and married there. “An explosive union from the outset,” is how the daughter describes the marriage. “My parents were like fire and water, and it was all quite chaotic.”

The family moved to Germany in the 1970s, to Wiesbaden, where Nicole Dubilier completed her German high school studies at the nationally renowned Helene-Lange-Schule, achieving an excellent grade average. “I really enjoyed school,” she says. And it wasn’t just physics, chemistry and biology that appealed to her – she was also fascinated by politics, the social sciences and humanities. Discussion, protest, conflict: the young Nicole Dubilier was interested in social developments, and still is today.

Against this background, her choice of biology as a subject is rather surprising. But “I also wanted to do something with my hands, something that linked physical and mental work.” So biology it would be, preferably marine biology. Her love of the sea runs deep and was forged by annual two-month-long family holidays on Fire Island, a long narrow island off the shore of Long Island. “Paradise for us children.” Her choice of subject was also influenced by another important factor: “Given the cha-
When she gets together with her colleagues as she does this afternoon, the atmosphere is constructive and friendly. The topic of discussion is the next trip to the Mid-Atlantic Ridge with the *Meteor* – a major event for all.

otic family life I experienced, I wanted to find order and logic somewhere. In science, I thought, two plus two always equals four.” A young seeker of the simple truth. She laughs.

She would later come to understand that research only really becomes fascinating when two plus two appears to make five – at the latest by the time she reached Harvard. Resolving such contradictions carries the promise of scientific renown – as was the case in the late 1990s when Olav Giere and Swedish taxonomist Christer Erseus accidentally discovered *Olavius algarvensis* off the island of Elba. The find immediately presented a puzzle: no matter how thoroughly Nicole Dubilier looked, she could not detect hydrogen sulfide in the sediment of Capo Sant’Andrea Bay. All previously discovered gutless oligochaete worms (annelids) lived in sulfide-rich sediments. Moreover, electron microscope images testified that at least two morphologically different bacterial species lived inside the worms.

Nothing added up correctly until Nicole Dubilier decoded the symbiont’s 16s rRNA gene. This gene is considered by experts to be a kind of molecular passport for a bacterial species. This led to a pioneering discovery for symbiosis research: a harmonious *menage à trois* – one host with two symbionts, with all of the partners benefiting.

**A DISCOVERY THAT SILENCED THE DOUBTERS**

Because there is little or no hydrogen sulfide in the Mediterranean sediment, *O. algarvensis* internalized a source of hydrogen sulfide by taking up a bacterium that produces sulfide from sulfate and generates energy in the process. The familiar sulfide-oxidizing bacteria use the hydrogen sulfide in turn as a source of energy.

A cycle thus emerges in which the two bacterial species exchange their metabolic products and ends only with the death of the host. This biological construct functions so admirably that the bacteria produce an excess of organic carbon compounds from carbon dioxide, with which they feed the worm. The microbes also relieve their host of all of the inconvenient waste products that it would otherwise have to excrete. “Simply ingenious,” says Nicole Dubilier. The worm makes itself largely independent of external energy sources and can populate new habitats that have little to no sulfide. “My most important scientific contribution – and no one believed it at first.” But the doubters were silenced.

Not least as a result of this discovery, Nicole Dubilier settled for the long-term at the Max Planck Institute in Bremen in 2001. “I had always wanted to work at this institute because it offers optimum working conditions.” These include her own research group – she now has her own funding as a research organizer – an office instead of a laboratory, and the opportunity to develop new perspectives with her colleagues. “They’re great,” she says warmly. “The teamwork is great fun.” Just what you’d expect from a symbiosis researcher.

When she gets together with her colleagues, as she does on this particular afternoon, the atmosphere is constructive and friendly. The topic of discussion is the next trip to the Mid-Atlantic Ridge with the *Meteor* – a major event for all. Meticulous preparation is required. And when, as now, they all beat around the bush because they don’t want to take over a routine task, the boss can also show her assertive side: “This has to be settled now, who’s going to do it?” She laughs.

Together with partners from the institute in Bremen and other institutes in Germany and abroad, Dubilier and her team regularly deliver outstanding results. The researchers have carried out in-depth studies on the *O. algarvensis* biotope using new molecular methods, and identified up to four different bacterial species, a *menage à plusieurs* involving two sulfate reducers and two sulfide oxidizers. Surprisingly, all four symbionts fix carbon dioxide. Why the redundancy? That remains unclear.

**A MODEL FOR A SELF-SUSTAINING BIOSPHERE?**

The different metabolic systems may perhaps be used in different sediments, in predominantly oxygen-rich upper layers of sand and in predominantly nitrate-rich deeper layers of sand. What is clear is that the worm has a regular symbiotic powerhouse built into its body. *O. algarvensis* shows how limited resources can be used through the cooperation of microbial communities that are tailored to each other’s needs,” explains Nicole Dubilier. The worm-bacteria symbiosis could thus provide a model for an almost self-sustaining biosphere. Such systems are required on a large scale by space travel, for example for long expeditions to Mars.
Nicole Dubilier always refers to such examples in response to the repeatedly asked question as to what purpose her “symbiosis science” could possibly serve. She then explains a bit about the carbon budget of the oceans and how the well-being of the sea is directly linked to species diversity, as well as how many of the processes associated with symbiotic bacteria could also be important for infection research. Yes, that too. More than anything else, Nicole Dubilier likes to enter unknown territory, and to keep an eye out for the unexpected, free from the ties of applied research.

The research of mussels in the dark of the deep sea is a comparatively new field for Dubilier. The bivalves carve out a rather miserable existence on whale corpses, hydrothermal vents and cold seeps where hydrogen sulfide can be found. They cultivate bacterial symbionts in certain cells of their gills and constantly pump a mixture of seawater containing oxygen and sulfides to them.

While studying this symbiosis, the Max Planck team also discovered bacteria that infect the nuclei of mussel cells. Interestingly, these parasites only penetrate into the nuclei of cells that do not have symbionts. “We therefore assume that the symbionts can somehow provide protection against infection,” says Nicole Dubilier. Her colleagues have now demonstrated the presence of such nuclear infections in commercially available blue mussels.

This makes researching this phenomenon somewhat less difficult, as shallow-water mussels are easier to access than their deep-sea relatives. Although, of course, the mere idea of an excursion to the world’s oceans immediately makes Nicole Dubilier’s eyes light up: “I am simply happy on the ocean.” She perceives it as a privilege to set sail at least once a year with the *Meteor* or the *Merian*, and to feel the ocean wind in her face.

**FASCINATING IMAGES FROM THE UNDERWATER WORLD**

But everyday life on board is sometimes hard. It starts early in the morning when the unmanned remotely operated vehicle (ROV) dives to the bottom of the sea and the scientist sits in the small dark container with the pilots who fly the ROV, watching the large screen showing the images it captures. “It’s like sitting in the middle of it yourself,” she says, with obvious enthusiasm. It is her job to tell the pilots what they should fish from the ocean sediment using the ROV’s manipulator arm – mainly mussels of late. “When it goes well, it’s great fun, and when it doesn’t go so well, you bicker.” And in the evening, when the ROV has come back up again, the work continues for the researchers, preparing and analyzing the animals and microbes in the ship’s laboratory. “My colleagues are surprised when they see that I still know my way around a laboratory,” says Dubilier. The job can take all night. “Holding a mussel from the depths of the ocean in your hands and sniffing it to see whether it smells of sulfide is incredibly satisfying.” And she loves the times when, after 20 hours of hard toil, completely tired and bleary-eyed, she gets together for an early morning chat with her equally exhausted colleagues.

She has only been participating in such trips again since her son turned eight four years ago. And only because she knows that her husband will take over the child caring in her absence. “He’s wonderful at it.” Here, too, she fosters the idea of cooperation. “I agreed with my husband that we would share child care equally, and we’ve stuck to the deal.” That’s Nicole Dubilier: mother, marine biologist, molecular biologist and microbiologist, the power-woman who wants to work until she’s 80, if she’s allowed to. And who just wants to be able to say “my team is doing the best research in the world.” She laughs. Of course.
A test for magnetic sensitivity: When Damien Faivre holds a test tube with a culture of magnetic bacteria first parallel and then perpendicular to a magnetic field, the medium’s turbidity changes. The bacteria’s magnetosome chains are indeed aligning with the magnetic field.
Magnets – Made by Microbes

Their medical importance would be considerable: magnetic nanoparticles such as those produced by magnetotactic bacteria could, among other applications, help detect tumors. Damien Faivre and his colleagues at the Max Planck Institute of Colloids and Interfaces in Potsdam are studying how these microbes work in order to harness their sophisticated mechanisms.

TEXT CHRISTIAN MEIER

A compass has always been an indispensable tool, not only for mariners wishing to reach their destination. Certain aquatic bacteria also navigate using Earth’s magnetic field. Their inner compass consists of a chain of tiny nanoparticles of the magnetic mineral magnetite.

These particles are produced by the bacteria themselves and have such unique magnetic properties that they are of great interest for medical and other technology applications. To date, however, only nature knows how they are produced. Damien Faivre, a chemist working at the Max Planck Institute of Colloids and Interfaces in Potsdam, hopes to unravel the secret with the help of his seven-man team. Once the researchers understand how the bacteria produce the nanoparticles, they hope it will be possible to develop a procedure to manufacture the particles, first in the test tube and later on an industrial scale.

In 1975, American microbiologist Richard Blakemore discovered that some aquatic organisms navigate along the Earth’s magnetic field, and named them accordingly: magnetotactic bacteria. However, these microbes do not seek out the North Pole, but the deeper regions of their aquatic environment. The magnetic field lines that lie away from the equator do not run parallel to the Earth’s surface but point downward. This guides the magnetotactic bacteria toward the deeper waters, where sediment and water mix. These oxygen-starved areas provide the ideal conditions for the bacteria to live and flourish. They are not able to use gravity for vertical orientation, since they are nearly as dense as water and thus do not perceive their weight.

GUIDED TO THE BOTTOM BY A COMPASS

The bacteria owe their compass to the magnetosomes, organelles consisting of a single particle of magnetite (Fe₃O₄) that measures less than 100 nanometers and is surrounded by a membrane to prevent the particles from clumping together. Some 20 magnetosomes form chains along protein fibers in the bacterium. They work like the needle of a
that should make chemical engineers sit up and take notice, as uniform particle size is an important mark of quality in nanoparticle production. “Not only that, but the bacteria can even control the shape of the particles,” adds Faivre. Some types of magnetotactic bacteria produce bullet-shaped nanoparticles, while others make needle-shaped ones. In fact, each type of bacteria creates its particles in a uniform shape. In short, these bacteria boast perfect internal quality control in the synthesis of magnetite particles.

The magnetic properties of the particles are of enormous interest for technical applications. “They display a remanence and coercivity that cannot be matched by artificially produced crystals,” says Faivre. These two physical parameters mean that the materials are magnetically hard, so their permanent magnetism remains very stable. This is a desirable property in many technical applications, for instance for magnetic data storage with unprecedented bit density.

MAGNETITE PARTICLES FOR TUMOR DETECTION

Other applications require uniform magnetic properties, and this is exactly what the bacteria’s magnetic nanoparticles offer, thanks to their uniform shape and size. Artificially created elongated magnetic particles could be used as a contrast agent in magnetic resonance imaging. Tissues holding the particles would show up as darker areas on the images. If the particles could be guided to a tumor, its location could be pinpointed at an early stage. The particles could also be used to ensure that drugs target the focused area of a disease. By positioning magnets outside the body, the particles would remain in those areas. The active substances bound to the particles would thus remain in the tissue where they are needed, instead of being flushed along in the bloodstream.

Although it is possible to create magnetite particles in the laboratory, these synthetic particles, unlike their biological counterparts, contain a small amount of oxygen. Damien Faivre’s team discovered this while...
studying the crystal structure and chemical composition of the magnetic nanoparticles using X-ray radiation from the Berlin-based synchrotron radiation facility, BESSY.

There are other difficulties with the synthetic production of magnetic nanoparticles: “So far, the available chemical processes cannot produce magnetic nanoparticles of uniform size and shape in environmentally friendly conditions,” explains Faivre. In this case, environmentally friendly would mean that the particles could be produced at room temperature, normal atmospheric pressure and without harmful solvents, instead of the energy-intensive conditions of high pressure and high temperature. With this in mind, Faivre wants to understand how nature manages to produce the uniform magnetic particles. “Nature shapes material down to the smallest detail, literally down to the smallest unit, the molecule,” he says. “We can learn from nature by trying to understand how natural models influence complex physicochemical and biological phenomena. As soon as the biological processes are fully understood, it should be possible to copy them in order to develop new materials.”

The researchers have already made some initial discoveries about how nature produces magnetite nanoparticles. Magnetotactic bacteria control the growth of the magnetic particles through a biological process called biomineralization – another way of saying biologically controlled crystal growth. Some 20 to 30 proteins called magnetosome proteins are responsible for this process. Biologists have also discovered which sections of the bacterial genome contain the genetic information that encodes the magnetosome proteins.

LAB TESTS REVEAL THE FUNCTIONS OF INDIVIDUAL PROTEINS

Damien Faivre and his team now hope to identify the roles played by individual proteins and their components in biomineralization. There are essentially two methods they can use in this quest. The first involves the generation of “deletion mutants”: bacteria in which a given gene has been deactivat-ed. Except for that single inactive gene, the genome of the mutant is identical to that of the wild type. As researchers study the differences between bacteria with the inactive gene and their unaltered counterparts, they can learn about the role of the specific gene. They check whether the deletion mutant produces magnetosomes, and if so, whether they occur in the same size and shape as in the wild type. This method does deliver worthwhile results, but “Since magnetotactic bacteria grow very slowly, the in vivo process is a very protracted one,” laments Faivre. It can take up to two years to study a single gene or protein.

For this reason, his team uses a second, more efficient method to shed light on the functions of the magnetosome proteins. They insert the gene of the relevant protein into the genome of the fast-growing bacterium Escherichia coli. The cell machinery of this microbe, induced by its genetic information to produce proteins, is stimulated to manufacture particularly large amounts of the implanted magnetosome protein. This is necessary so that researchers can achieve the same protein concentration in the test tube as occurs in the far smaller magnetotactic bacterium.

Finally, researchers isolate the proteins and study their properties in the test tube. To this end, they mix the pro-
tein with iron compounds that, like magnetite, contain divalent and trivalent iron, gradually altering the pH of the solution until its components are precipitated and magnetite particles are formed. During this process, the protein influences the size or the shape of the particle being formed. “This method enables us to study a single protein in three to four months,” says Faivre.

It is clear from the outset that not all magnetosome proteins are equally important for magnetosome production, so before they begin to study individual proteins, the researchers gather information on which ones are more likely to play key roles in biomineralization. This saves time by avoiding unnecessary test tube experiments.

One of the screening tools used for protein preselection is bioinformatics software. This enables the team to identify similarities between the genes of different magnetotactic bacteria. Any such similarities indicate important genes and thus important proteins. Another method used is bio-combinatorial engineering. Here, the researchers study which peptides, or protein portions, bind to the surface of magnetite crystals. These peptides enable direct contact between proteins and magnetic particles, and could therefore be components of important magnetosome proteins. At the very least, the direct contact with the magnetic particle would imply that the relevant protein must have an important function. The peptides are then translated into DNA sequences – that is, the language of genetic information. Using these sequences, a computer program scans the genome of magnetotactic bacteria to identify the associated proteins.

A PROTEIN THAT CONTROLS PARTICLE SIZE

So far, Japanese and American researchers have clarified the role of one magnetosome protein in the synthesis of magnetite particles inside magnetosomes. The protein bears the unimpressive name Mms6 and is found only in magnetotactic bacteria. Mms6 is located in the membrane surrounding the magnetite particle, and scientists have discovered that it codetermines the size of the magnetic nanoparticles. To date, it is the only protein known to play a decisive role in vitro in controlling particle size. Scientists have yet to discover any proteins that determine the shape of the magnetite crystals.

In studying Mms6, researchers happened across another significant phenomenon: the peptide at one end of the protein, consisting of 25 amino acids and therefore constituting only a small portion of Mms6, influences the size of the magnetite particle. Faivre explains that this finding is vitally important, “because the artificial mass production of proteins using host organisms is limited, whereas synthetic peptides can be produced in practically unlimited quantities.”

Meanwhile, the search continues for proteins involved in the formation of the magnetic nanoparticles. “Up to now, 20 protein candidates have been identified in the magnetosome membrane of the magnetotactic bacterium M. gryphiswaldense, and it is assumed that they have particular effects on the size and shape of magnetite crystals,” explains Faivre.

Some of these candidates are currently being studied by Faivre’s team at the Max Planck Institute in Potsdam. The team is also researching how individual magnetosomes link together to create a chain so that, bit by bit, the tiny compass needle is formed to guide the microbe to its food. They have shown that the formation of the chain involves a complex interaction of genetically controlled processes and magnetic forces. One of the methods used was “ferromagnetic resonance spectroscopy,” which is similar to nuclear magnetic resonance, FMR, as it is called, allows the
magnetic properties of solid bodies to be examined. It can show, for example, the preferred orientation, if any, of a magnetized crystal. It allows scientists to study both the individual magnetite particles and the particle chains.

Faivre and his colleagues hope that their research will identify all the proteins and other biological components (especially lipids) that direct the biomineralization of magnetite particles. The key for them is to understand the different roles the proteins play in particle synthesis. “Then it would almost be possible to make magnetic particles measuring 20, 50 or 100 nanometers in diameter to order, even specifying that they should be, say, round or needle-shaped,” says the biochemist. It would simply be a case of selecting the relevant proteins, like tools from a toolbox. For now, it is only a dream – but the Potsdam research team has taken the first steps toward making it a reality.

GLOSSARY

Magnetosome
A magnetite particle enclosed by a membrane. Each particle measures less than 100 nanometers; different types of magnetotactic bacteria produce them in various characteristic shapes and sizes.

Magnetotaxis
The ability of some life forms to orient along the Earth’s magnetic field.

Magnetic resonance imaging
Also called nuclear magnetic resonance. A procedure based on the fact that some atoms, such as hydrogen, have a magnetic moment. Their behavior in a magnetic field depends on the tissue in which they are located. This allows different tissue types to be identified. Certain magnetic substances can be used to enhance the contrast between them.

Biomineralization
Organisms use organic and inorganic substances to produce inorganic minerals and compound materials very precisely, controlling their production through biochemical processes. Notable examples, apart from magnetosome crystals, include mother of pearl and the silica skeletons of diatoms.

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In many regions of the Earth, agriculture is threatened by a lack of water. Therefore, new plant varieties must be developed that are especially resistant to drought. For scientists at the **Max Planck Institute for Plant Breeding Research** in Cologne, barley is an ideal model for understanding the genetic strategies plants use to adapt to drought.

**TEXT** **MARIA VON KORFF, MAX PLANCK INSTITUTE FOR PLANT BREEDING RESEARCH**
Along with einkorn wheat, emmer wheat, flax and lentils, barley is one of the oldest cultivated plants. It was first cultivated about 10,000 years ago, when humans began to grow and select plants for food production. The elite barley varieties cultivated today are derived from the two-row wild form *Hordeum vulgare* L. *ssp. spontaneum*. The genus *Hordeum* comprises a total of 30 different wild varieties. After corn, rice and wheat, barley is the fourth most important cereal in the world and has the widest geographical distribution. It grows in the dry regions of the Middle East, in Tibet at altitudes of over 4,000 meters, in the sub-tropics and at the polar limit of grain cultivation.

Today, most variants still grow where barley first originated and was later cultivated by humans – in the Middle East region known as the Fertile Crescent, and in North and East Africa. Barley thus holds great genetic potential for adaptation, which can be exploited to breed resistant varieties.

Barley varieties that grow in very dry locations have developed special protective mechanisms. Wild barleys from the Fertile Crescent store more anthocyanins in their stems, leaves and spikes. These pigments give the plant a red color and protect it from excessive sunlight, like a sunscreen. A dense cover of hairs on the stems and leaves also reflects the sunlight. In addition, leaf hairs trap the moist air above the leaf surface and thus reduce transpiration and water loss from the plant. Barley can also adapt its life cycle to the surrounding temperature and to the available water. In dry, southern regions, for example, barley flowers early in the spring, ensuring that it completes its life cycle before the onset of the summer heat. In temperate latitudes, in contrast, barley develops more slowly, exploiting the longer growth period. In Germany, barley grows annually as spring barley or, like winter barley in the Mediterranean area, over the winter.

Today, four major genes are known in barley that induce flowering when the day length and temperature are ap-
There are several phases in the development of barley flowers. First, vegetative growth tissue (meristem, A) forms the flower meristem. B. From this is formed the spike with the meristem primordia (C), which then develops into fertile florets (D) as the stem elongates. The duration of each of these phases varies independently of the others and depends on both the environment and the genetic makeup of the plant. Each developmental phase affects yield in a different way: the number of spikes per plant is determined at the early developmental stage before the spike is completely developed. The number of grains per spike is determined primarily during stem elongation.

**MUTATIONS DELAY DEVELOPMENT IN BARLEY**

In contrast to winter barley, the Ppd-H1 gene is mutated in spring barley and is therefore inactive. Moreover, the Vrn-H2 gene is deleted. Flower development is thus delayed in spring barley under long photoperiods, and does not require vernalization, allowing the plant to make use of the long growth period in temperate climates.

We are looking for genes that influence individual phases of flower development. This would allow flowering to be fine-tuned in different environments in order to increase yield. Drought shortens the time to flowering in barley. Long photoperiods affect primarily the later reproductive stages, stem elongation and spike development. The extensive collection of wild barleys from the Fertile Crescent held at our institute is a valuable source of new genetic variants, as systematic breeding of high-yielding varieties since the beginning of the last century has increasingly narrowed genetic variation in our elite varieties. In terms of evolutionary history, though, this is a short period of time, and most of the natural ancestors of our recent cultivars can still be crossed with them.

We investigated around 900 varieties of wild barley and crossed those that vary in their reproductive development with German barley cultivars. This gives rise to barley lines with differences in reproductive development and thus yield structure. The underlying traits and gene forms that cause this variation are passed on to the offspring. With the aid of molecular markers, we identify those regions in the barley genome that control spike development. As the barley genome has not yet been decoded, we align the identified genomic regions with the rice reference genome, which has already been sequenced. This allows us to identify flowering time genes in barley, as rice and barley are characterized by a similar gene content and gene order on the chromosomes.

**FROM THE LABORATORY TO FIELD RESEARCH**

We also use findings from plant genome research on *Arabidopsis thaliana* because the pathways that trigger flower development have already been thoroughly investigated in this plant. As many of the genes and functions involved are also functional in barley,
Scientists test the positive characteristics of wild barley, such as stress resistance, in crosses between wild and cultivated barley in the field. Plants with slow stem and spike growth form particularly fertile flowers and grains and thus provide a better yield.

it is possible to draw conclusions about the genetic regulation of flower development in barley.

Studies on the regulation of flowering time in barley are first carried out under controlled conditions in the greenhouse, where we test the effect of individual environmental parameters – day length, temperature and water – on the individual genes and traits. However, we have to study the effects of the different gene forms in wild and cultivated barley in the field before they can be applied in plant breeding. For this, we work with the Center for Agricultural Research in the Dry Areas (ICARDA) in Syria; ICARDA has the global mandate to research barley and agricultural production in semi-arid regions.

At this international agricultural research center, we are examining, under natural conditions in the field, the strategies barley uses to adapt to drought. We then carry out detailed genetic studies at our institute to identify the genes and gene regions that increase the crop yield of barley under dry conditions. This information is not only important for farmers in the Middle East, it also serves the breeding of cultivated plants in other parts of the world where they must adapt to increasingly dry summers.

We are already experiencing an accumulation of extreme weather conditions in connection with climate change. Global climate models are forecasting that, by the end of the 21st century, the Earth will be 2 to 5 degrees Celsius warmer, and that heat waves, drought periods, floods and heavy precipitation will increase. The developing countries in sub-Saharan Africa and in Asia will be particularly affected. Calculations by the Intergovernmental Panel on Climate Change suggest that harvest yields in these areas could be halved by 2020.

Central and Northern Europe are among the areas that might potentially benefit from climate change, as heavier winter precipitation and higher average temperatures could increase agricultural production. For this to happen, however, today’s crop plants must be adapted to the new climate conditions. This task is becoming increasingly difficult, as it is not the seasonal mean value that decides the quantity and quality of harvests, but primarily the climatic extremes. For example, continental and southern regions of Europe are already suffering from longer dry periods in the summer months. But also in Germany, grain harvests, with the exception of winter
barley, have been stagnating for the past ten years. Therefore, also scientists in Europe are researching the development of plant varieties that maximize yield per unit of water used.

In many areas of the Earth, water is in short supply. Water availability is thus the most important factor in agricultural production throughout the world. Increasing food production in the future depends primarily on whether agricultural areas can be supplied with sufficient water. In 2008, precipitation was less than 150 mm in many of the farming areas in the Fertile Crescent.

Under these conditions, drought-resistant barley varieties still produce approximately 500 kilograms per hectare. To a German farmer with a yield of 60 to 100 tons per hectare, this would mean an almost total crop failure, but to a self-sufficient farmer in many regions of the Middle East, it means subsistence. They are then not forced to sell their livestock and look for work in the city. The most important objective of the breeding research in Cologne and Syria is thus to decode the genetic basis for stable yields under extreme growing conditions.

Against this backdrop, in the future, stable or even rising agricultural yields will depend on the successful development of new cultivars. The cereals that will become increasingly important are those that are already an integral part of extensive farming systems and that, due to their low water use, grow in dry conditions – and these are mainly winter and spring barley.

### Glossary

**Spring/winter barley**

Winter barley requires a cold period to develop inflorescences. It is sown in late September in Central Europe and harvested in July. Winter barley has a 20 percent higher yield, as it optimizes the use of moisture in winter. Its share of barley production has thus been on the rise for years. Spring barley, in contrast, is sown in March or April and harvested in August. Winter barley is used mainly for animal fodder; spring barley is used for malt.

**Vernalization gene**

(Latin *vernus* – spring) A gene that inhibits flower development prior to sufficient exposure of the plant to temperatures below 10 degrees Celsius. In some plant varieties, there can be months between the cold period and flower development. Most cereals need a cold period before they flower.

**Fertile Crescent**

One of the regions in which humans originally settled and transitioned from the nomadic lifestyle to farming and livestock breeding. It covers parts of Lebanon, Syria, Iraq, Iran and southeastern Turkey. Some of the globally most significant cultivated plants, such as wheat, barley, lentils and peas, and four of the five most important domestic animals were domesticated here. The closely related wild forms of crop species are still widespread in the Fertile Crescent.
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Networking Diversity

For Steve Vertovec, Director at the Max Planck Institute for the Study of Religious and Ethnic Diversity in Göttingen, basic research need not necessarily be confined to the ivory tower. His Department of Social Diversity was responsible for contributing hard facts and suggestions for the city of Frankfurt’s newly drafted integration and diversity plan.

Text Birgit Fenzel

While a journalist from one of the smaller Berlin daily newspapers penned the phrase: “peace, love and falafel” in connection with a piece on integration. If the way to the heart truly is through the stomach, then, given the number of kebab shops, pizza stands and sushi bars that crowd our city centers, the issue should actually have been settled long ago. That the problem is far from solved, however, is clear from the fact that even acknowledged municipal integration policy experts such as those working in Frankfurt are still seeking new ways for people from different cultures to coexist constructively.

The metropolis on the Main River has a fair amount of experience in such matters. In the late 1980s, municipal authorities came up with the idea of a Department of Multicultural Affairs – commonly known by its German initials, AmkA. The task of this department was, and is, to promote the peaceful coexistence of people of German and foreign nationality, as well as differing origins and religions. This move contrasted strongly with the prevailing attitude at the time, when most citizens generally preferred to ignore the social reality of immigration. The concept of integration was also taken to mean that the immigrant minority should adapt themselves to the dominant – German – culture of the majority.

NEW PLAN CALLS FOR A RADICAL CHANGE OF COURSE

To mark the 20th birthday of AmkA, Frankfurt’s multicultural pioneers set to work on a special anniversary “present”: a 236-page draft of an integration and diversity plan in which guest contributors describe the social realities in the city from their own perspective. The scientific elements of the plan were entrusted to cultural anthropologist Regina Römhild, now a professor at Berlin’s Humboldt University, and Max Planck Director Steven Vertovec.

Conceived as a blueprint for an open discussion with the citizens of Frankfurt, the work contains some surprises. Aside from the fact that it makes AmkA appear at least nominally obsolete, it suggests a radical change of course.

On the basis of Vertovec’s observations, the standard multicultural view of people from different cultures living side
Thanks to its traditional role as a center of trade and its interwoven transportation, financial and business infrastructures, the city of Frankfurt am Main may fairly be described as Europe’s most important urban hub.

by side with one another no longer fits with the social conditions he has encountered – and not just in Frankfurt. As a social anthropologist for more than two decades now, he has been studying the phenomena of international migration, cosmopolitism and multiculturalism in the major cities of the world.

In 2007, Vertovec became a Founding Director at the Max Planck Institute for the Study of Religious and Ethnic Diversity, where he established the Department of Social Diversity. Today, the unpretentious new building on the edge of Göttingen’s inner city is populated by young scientists of various disciplines who make use of the latest techniques and methods in sociology, social psychology and anthropology to gather data on urban populations. The material they collect will help them analyze the changing forms, dynamics and consequences of social coexistence.

The invitation from AmK A in Frankfurt to join cultural anthropologist Regina Römhild in contributing to the scientific basis of the plan fit in very well with 52-year-old Vertovec’s own plans. “Frankfurt interests me not least because it is a global city,” he says, citing another reason for his willingness to take a general inventory of the city’s immigrant society. Thanks to its traditional role as a center of trade and its interlinking transportation, financial and business infrastructures, Frankfurt am Main may fairly be described as Europe’s most important urban hub. Despite having a relatively small population of some 670,000, Frankfurt is nevertheless a “city of superlatives,” the only one in Germany to rank alongside such global cities as New York, Tokyo and London.

In the view of the social anthropologist, the link between these global cities is not limited to their role as symbols in the global economy – a role they acquired by virtue of their position as the headquarters of multinational companies and institutions, as financial centers and international transport hubs. Vertovec, who has an eye for diversity, also sees parallels in their social structures.

FRANKFURT IS GERMANY’S MOST INTERNATIONAL CITY

Like all global cities, Frankfurt also has a markedly international population: 40 percent of its citizens are either migrants themselves or have an immigrant family background, making it the most international city in Germany, according to the Max Planck scientist. The mix of countries from which these migrants originate is as colorful as previous research has revealed in other global cities.

From a pile on his desk, Steven Vertovec pulls out a chart that was plotted using statistical data on Frankfurt’s population: a pie with many colored slices showing the percentage breakdown of the population by country of origin. Vertovec already has a chart in his drawer that was plotted during his study in London – a very similar chart, in fact, since there are almost exactly the same number of nations coexisting in the two cities: 179 in London, 176 in Frankfurt.

“What we have found here contradicts the common perception that the larger groups always originate from Turkey and southeastern Europe,” the scientist explains. On the one hand, the traditional countries of origin of the first generation of “Gastarbeiter” (foreign workers) – particularly Turkey and Italy – still form the largest segments of the chart. “But their proportions are declining in the face of large numbers of new immigrants in small and very small groups from all over the world,” says Vertovec, describing a statistical trend that does not match the image
Linguistic diversity: The media, too, have adjusted to the large number of foreign citizens in Frankfurt. This photo shows a newsstand in the city's Gallus district.

presented by previous surveys, such as the Frankfurt integration study of 2008.

However, this relatively recent work differentiated only between “non-Germans” of various nationalities and “Germans,” with a distinction drawn even between Germans with and without an immigration background. As Vertovec and Römhild have discovered, such statistical categories do not match the reality.

On the contrary, they found a dynamic variety of social realities in Frankfurt on a par with that which Steven Vertovec had already identified in London as a basic feature of “new migration.” In London, as in Frankfurt, immigrants from the traditional countries of origin – in this case Britain’s former colonies and the Commonwealth countries – have long since ceased to form the largest migrant groups. The proportion of new citizens from the Middle East and the European Union is steadily growing larger.

When he published his study of London in 2007, Vertovec coined the term “super-diversity” to describe this new pluralism – a phrase that, at the time, did not appear in the sociological lexicon. His intended meaning of the term is not restricted to the observation that a large part of society has first- or second-hand migration experience. Describing the broad reach of the phrase, he explains that super-diversity is diversity at all social levels – but especially within individual groups.

As examples of this comprehensive heterogeneity he cites differences in ethnicity, language, religious traditions, regional and local identities, and cultural values and practices. In addition, within each group of immigrants there are a variety of different social strata and claims to residence that are
associated with the reasons that brought the individuals to the city. As the center of the European financial and service industries, Frankfurt’s economic success is closely linked to mobility and immigration, insofar as the city not only offers jobs for highly qualified immigrants at foreign and multinational companies, but also employment in related sectors and services.

A FOCUS ON ORIGIN CONCEALS SOCIAL DIFFERENCES

As a result, there are a variety of migration paths that create a distinction even between individuals of the same geographic origin. As Vertovec points out, offering food for thought, there is a difference between seeking asylum and coming to study in Frankfurt. He has identified every possible migration path in Frankfurt: from a rising number of seasonal workers and nursing staff to foreign specialized and managerial staff and educational migrants with grants and student visas through to refugees and asylum seekers and those who have come simply to join their families.

The immigrants’ needs are as varied as their motives. “The same applies to the nature of their contacts with others and with public institutions,” says Vertovec. Sometimes people of differing origins who nevertheless migrated by the same route have more in common than those who share the same nationality but whose intentions in coming to Frankfurt vary. Focusing solely on groups of shared national origin conceals these social differences within the group, Vertovec believes. “The resulting statements about, say, ‘the Turks’ tell us as little about the underlying social strata, lifestyles or religious attitudes of the community in question as do comparable statements about ‘the Germans.’”

As another key feature of Frankfurt’s super-diversity, Vertovec and his colleague Regina Römhild identified extreme variations in the legal status of the city’s immigrants, as well as in some cases of glaring contrasts in their social situations. One of the major causes, they believe, lies in the amendments to national immigration law. However, the more restrictive demarcation of Europe’s external borders and the regulations limiting third-country immigrants and refugees have also led to an “immense spectrum” of widely differing legal statuses ranging from a lawful, long-term secure entitlement to residence to an unlawful status that is devoid of all legal security.

Even experts begin to flounder when faced with the variety of criteria that determine how long an individual may stay here and the hierarchy of entitlements and restrictions. Vertovec knows this to be the case from discussions with a Frankfurt-based lawyer specializing in these matters who described the legal situation as “highly confusing.” Other factors that affect the social situation of many migrants also include their educational backgrounds and professional and vocational qualifications, and thus also their prospects in the employment market.

LOCAL AUTHORITIES MUST MAKE A GREATER COMMITMENT

“However, given the continuing lack of recognition accorded to foreign educational qualifications, what credentials they do have are often not accepted,” Vertovec says, describing another problem faced by many immigrants. This applies especially to individuals of restricted and precarious legal status. Their social situations are also particularly influenced by whether they receive support from social and family networks and local aid organizations.
Vertovec sees a considerable need for action in this respect, and not just in Frankfurt. A greater commitment of local authorities to the socially weakest immigrants should not only be considered a basic human right, it is also essential to any form of integration. Social status, across the board but especially in the case of illegal or legally undefined immigrants, is crucial to how these persons enter the country, settle down and obtain employment, find homes and access schools, social services, health care and other public services. It affects whether or not they remain tied to their place of origin and how they interface socially and culturally with other migrants and with the German population.

What the researchers found when they analyzed data from the register of the city’s residents is likely to be of interest in Frankfurt and beyond. They looked at the geographic distribution of super-diversity across the entire urban area. “Our findings clearly show that it is not concentrated locally, but distributed widely throughout the city,” says Steven Vertovec. In the researchers’ opinion, these findings plainly contradict the widespread fear of urban “ghettos” and “parallel societies.”

The statistical fact that, during the period from 1998 to 2006, districts with a traditionally high proportion of foreigners actually experienced the steepest fall in this proportion also contradicts the idea of consolidated ethnic structures. As the social anthropologists have observed, the adjacent northern city districts saw the greatest increase. Here, too, in the case of surveys like these, it pays to look into the data a bit more deeply. “There are differences in the pattern of settlement depending on whether one distinguishes between non-Germans and Germans with an immigration background, or between people with and without personal migration experience,” Vertovec explains.

Whereas actual immigrants prefer to settle on the north bank of the Main, predominantly near the railway station and in the Gallus district, Germans with a migration background evidently opt mainly for districts such as Griesheim and the northwestern precincts, as well as the heavily populated areas in the north of the city.

Considering these differences, it becomes clear that an integration plan focused solely on the criterion of “foreign nationality” falls short of the mark. An integration policy that takes account of the difference between indications of immigration and actual immigration experience and the specific distribution of the population would more closely reflect social reality and thus be more effective.

MANY MOVE IN – JUST AS MANY MOVE OUT

A look at the statistics revealed another feature of Frankfurt that could well set a record: “Around 300,000 people – equal to around half the entire population – come into the city each day and then head back out. This gives Frankfurt the highest proportion of commuters in Germany,” says the Max Planck researcher. The marked predilection for moving is also worthy of the record books. According to data from the register of residents, over a period of about 15 years, the number of people who moved into and out of Frankfurt was equal to the city’s average population. A particularly high level of fluctuation among the population need not necessarily lead to social instability, Vertovec believes. On the contrary, he sees advantages for the city. “New consumers and new people in paid employment tend to stimulate the local economy.”

Vertovec also sees opportunities rather than risks in the transnational orientation that is increasingly evident in Frankfurt and other global cities. In recent years, the inexpensive international tariffs offered by telephone companies, coupled with affordable travel costs and the Internet, have enabled migrants, more than ever, to maintain close ties with people and places abroad. A common fear is that such a transnational orientation will be accompanied by an absence of any feeling of belonging and a lack of loyalty to the immigrants’ host society.

Precisely this fear is often one of the reasons for intensified integration efforts that are aimed at persuading immigrants to “unambiguously” adopt their new homeland both culturally and socially.

There is a colorful mix of nations represented in global cities. Street parades that celebrate ethnicity are part of the typical pattern of life in cities known for their super-diversity.
and socially. “The fact is, however, that cultural and social scientific research has long since demonstrated that life in late modern societies is generally accompanied by multiple orientations and identities with increasingly transnational dimensions – a phenomenon that is by no means restricted to immigrants,” says Vertovec. As he is aware from numerous interviews, these people feel a bond with their countries of origin and their communities, and reap the benefits of new, low-cost communications. Vertovec continues: “Nowadays, they have the opportunity to cultivate and intensify such feelings, while at the same time building a new life in their new home with a new livelihood, social ties and political commitments.”

As to the future activities of Frankfurt’s integration managers, networked diversity seems to the researcher to be a more up-to-date alternative to the multiculturalism of the early years. In practical terms, many of the suggestions put forward as a follow-up to past work essentially involve bringing people together to talk to one another and exploit shared interests to reduce the barriers between them. Describing the potential new mandate for integration in Frankfurt, the researchers believe that, given the “considerable expertise” and plentiful existing contacts to various groups that AmkA can call on, it is in a “unique position” as a public agency to play a leading role in the development of contacts and networks.

HOBBY GARDENERS CREATE A MINIATURE PARADISE

For example, AmkA could identify and stimulate discussion on overarching issues that affect and demand a commitment at all levels of society, or develop initiatives of general local interest – such as setting up and operating a community or youth center, organizing street parties, working with children, encouraging local flea markets, or helping people to jointly acquire knowledge or special skills.

Building social connections at the neighborhood level is another of the long list of suggestions that an agency might undertake. AmkA can draw on a wealth of experience garnered from the many effective projects it has carried out over 20 years of integration efforts. A successful example cited by the researchers is Frankfurt’s “Intercultural Gardens” initiative, through which hobby gardeners of widely varying provenance come together to create colorful flower and vegetable paradises.

In many cases, all that is required of the city is to provide suitable space. “There is often no shortage of ideas for joint activities. What is lacking are the resources and the room to turn these ideas into reality,” says Vertovec. This
also explains why public institutions should use the options available to them to promote durable contacts and interaction. In turn, contacts and interaction of this kind should be developed into more sustainable social networks that transcend ethnic and religious boundaries and legal restrictions and integrate refugees, asylum seekers and people with limited or undefined legal status on an equal level.

Ultimately, it is a question of bringing people together to talk to one another and exploit shared interests in order to lower the barriers between them. “The discussion we have prompted about how and where immigrants live, and the changes and coexistence in the districts of the city, is motivated by a concern to strengthen the district-specific relevance of integration policy,” explain Steven Vertovec and his colleague Regina Römhild. Precisely what that means for any given district or neighborhood can only be decided for each specific place in discussion with those directly involved.

What is more, a common language is needed for all of these strategies and the actions and programs that may potentially develop. “From this perspective, the policy of networked diversity can go hand in hand with help in learning the German language,” explains Steven Vertovec. Then again, he doesn’t want to see the bar set too high. It is not so much a question of acquiring general linguistic competence as of learning the language skills needed to interact in a variety of everyday situations, for instance at work, in conversation with other parents at school, and when dealing with public institutions.

In his field studies of social diversity, Vertovec once came upon a scene at a flea market by chance that he happily relates in this context, as it conveys the image he has in mind: “Two men, neither of whom could speak German terribly well, were discussing a tool that one of them wanted to sell and the other was keen to buy. They praised its qualities and talked about the price, cracked jokes and got on splendidly in a language that was clearly not their mother tongue and of which they had only a moderate command.” A good example of what a successful policy of networking might look like in real life.

**Call for Nominations**

**Max Planck Research Award 2011**

The International Research Award of the Alexander von Humboldt Foundation and the Max Planck Society

The Alexander von Humboldt Foundation and the Max Planck Society jointly confer the Max Planck Research Award, which is funded by the German Federal Ministry for Education and Research, on exceptionally highly-qualified German and foreign scientists. The researchers are expected to have already achieved international recognition and to continue to produce outstanding academic results in international collaboration – not least with the assistance of this award.

Every year, two research awards are conferred on internationally renowned scientific researchers. One of the awards should be given to a researcher working in Germany and the other to a researcher working abroad. As a rule, each Max Planck Research Award is endowed with 750,000 Euros. Nominations of qualified female scientific researchers are especially welcome.

On an annually-alternating basis, the call for nominations addresses areas within the natural and engineering sciences, the life sciences, and the humanities.

The Max Planck Research Award 2011 will be awarded in the area of engineering sciences in the field of **Intelligent Systems**

Intelligent systems integrate information acquisition and processing, as well as target-oriented action, also under diffuse boundary conditions. Research in engineering science that deals with intelligent systems focuses on, among other things, making rational and human cognitive performance and procedures available for artificial inanimate and bio-hybrid systems by machines.

The Rectors/Presidents of German universities or research organisations and the scientific heads of institutes of these organisations are eligible to nominate candidates. Nominations must be submitted to the Administrative Headquarters of the Max Planck Society or the Alexander von Humboldt Foundation. Direct applications by candidates themselves are not possible. The deadline for nominations is 20 October 2010.

Please find further information at either www.humboldt-foundation.de or www.mpfp.mpg.de

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**GLOSSARY**

**Transnationalization**
A scientific term that seeks to embrace the social, cultural, political and economic ties that migrants maintain with their countries of origin.

**Super-diversity**
A plan describing the change in international migration and the population structure of the destination countries since the 1980s. Instead of large groups of migrants from a small number of countries, there are now small groups arriving from widely differing places of origin.

**Global cities**
A term coined by urban sociologist Saskia Sassen. Global cities are mutually networked centers of finance and services that fulfill central control functions in the global economy.
Everything started with the mythical figure of Prometheus: Zeus, father of the gods, had taken fire away from mankind. In order to return it to them, Prometheus held the stalk of a plant into the sky and ignited it with the sparks flying off of the carriage of the sun god, Helios. The thought of capturing solar fire has fascinated mankind ever since. Researchers worldwide, including the staff of the Max Planck Institute for Plasma Physics (IPP) in Garching and Greifswald, are now working on igniting the solar fire on Earth itself, and making it available for energy generation. The challenges of this undertaking are much greater than the pioneers of fusion research anticipated a few decades ago.

In the late 1940s, scientists began investigating how energy could be obtained from nuclear fusion. Back in 1929, physicists Fritz G. Houtermans and Robert d’ Escourt Atkinson suggested that solar fire originated from the fusion of light atomic nuclei. Ten years later, Hans Bethe and Carl Friedrich von Weizsäcker described the reaction cycle during which hydrogen nuclei fuse to helium at around 15 million degrees Celsius in the Sun’s interior. This created the theoretical foundation for fusion research.

In order to initiate nuclear fusion under terrestrial conditions, the researchers would have to succeed in confining and thermally insulating an extremely thin, ionized gas – a plasma – comprising the hydrogen isotopes deuterium and tritium, and heating it to temperatures of more than 100 million degrees. Only at these temperatures is the speed of the particles so high that two positively charged atomic nuclei overcome their mutual repulsion and fuse with each other. If this succeeds, the energy yield is huge: 1 gram of fuel could provide the same amount of energy as the burning of 11 tons of coal.

The enthusiasm was great at first – especially since the supply of the components for the fuel was almost limitless. Deuterium is present in the oceans, and tritium can be produced from lithium, which is found in rocks. In 1955, experts thought that mankind’s energy problems would be solved once and for all in 20 years. In Los Alamos, where British scientist James Tuck called his planned experiment the Perhapsatron, the scientists’ reaction was more subdued. Tuck wasn’t completely on the wrong track, as it soon emerged that the fleeting plasma was hard to harness. A large number of instabilities interfered with the magnetic confinement and caused the charged particles to escape. In the late 1950s, the scientists resigned themselves to the fact that the road to fusion would probably take longer than they hoped.

At that time, Germany also had plans to expand fusion research. At the Max Planck Institute for Physics in Göttingen, the key fields included general plasma physics and nuclear fusion. Werner Heisenberg, the then Director of the institute, championed the expansion of the “work in the field of thermonuclear research”.

Perhapsatron with a Future

Nuclear fusion could safeguard the energy supply of the future. The shining example is our Sun, which obtains its energy from the fusion of light atomic nuclei. Fundamental findings for the development of this new energy source originate from the Max Planck Institute for Plasma Physics (IPP) in Garching, which celebrates its 50th anniversary this year.
stellarator to confine hot plasma. And this although the reaction vessel and had been manufactured tokamak. The results are anything developed thus far. «

of Earth (…) In terms of daring, this problem is set to surpass the interior of the Sun and most stars, for the peaceful development source that nature can provide, which can be found in the Ultimately, one will start to (...) utilize the greatest energy of the European fusion research program ever since. In the early years, researchers had no idea which approaches would lead them to their goal. The Garching-based scientists therefore conducted their research on a broad front to test various methods of confin-

Trends in Science, Dec 8, 2022, 19:13

Süddeutsche Zeitung from November 22, 1955

Ultimately, one will start to (...) utilize the greatest energy source that nature can provide, which can be found in the interior of the Sun and most stars, for the peaceful development of Earth (…) In terms of daring, this problem is set to surpass anything developed thus far.»

ing the plasma. Plasma physicists all over the world also tried out many ideas for harnessing the fleeting mixture of particles – and rejected most of them.

Two types of systems survived the selection process: the stellarator, whose principle harks back to the efforts of Lyman Spitzer, creates the magnetic field confinement solely by means of external coils; the tokamak, on the other hand, which was invented by Russian physicists Igor E. Tamm and Andrei D. Sakharov, also had a current flowing in the plasma that heated the fuel at the same time. Since this plasma current is generated in pulses by a transformer, tokamaks can operate only in pulsed mode, while stellarators are suitable for continuous operation.

However, the experimental progress achieved with both types of devices remained unsatisfactory in the 1960s. Above all, the physicists were concerned about the particle losses, which were far too high. Toward the end of the decade, the scientists seemed to have reached a dead end – until, in 1968, news arrived from Russia: researchers reported that, with their T3 tokamak, they had achieved values for the plasma temperature, density and confinement time that exceeded all results obtained thus far. Scientists in other countries were initially skeptical. Therefore, in early 1969, a British team traveled to Moscow for the sole purpose of checking the information provided by their Russian colleagues. They took along five tons of physics equipment for their new type of laser measurements. When the measurements not only confirmed the reports, but even bettered some of the reported findings, tokamak euphoria erupted in the scientific world.

Scientists in Germany couldn’t ignore the new developments. In 1973, the first tokamak Pulsator went into operation at the IPP; at the same time, the scientists continued to experiment with their stellarators. And they were also working on another bold idea: they wanted to use the Asterix high-energy laser to bombard tiny, frozen deuterium-tritium pellets in free-fall with focused laser beams. The energetic light flashes would compress the pellets to an extreme degree within one billionth of a second and bring them to ignition temperature, detonating them as “mini-hydrogen bombs” and thus releasing energy.

In 1974, however, the decision was made to focus the work at the IPP exclusively on the magnetic confinement of plasmas, and to halt the research into laser fusion that had been started in 1967. On January 1, 1975, the laser fusion was spun off into a project group from which the new Max Planck Institute of Quantum Optics evolved in 1981.

In 1980, the IPP achieved a world premiere when it successfully used the Wendelstein 7-A stellarator to confine hot plasma without additional plasma current; up to that point, this had succeeded only with cold plasmas. “Garching shows stellarators may be good after all,” was the headline that followed in the journal Physics Today. And this although the reaction vessel and the helical solonoids of Wendelstein 7-A had been manufactured in the institute’s workshop as a short-term interim solution – which then remained for almost a decade, gaining no small degree of fame.

The researchers were able to score their next big success in 1982: the ASDEX tokamak provided the proof that the heat insulation could be doubled by using a special magnetic field arrangement (called a divertor). The physicists thus achieved a plasma state with particularly good heat insulation, the so-called H-mode. Fusion systems around the world have been working with a divertor ever since.

Today, the IPP is the only institute that investigates the tokamak and stellarator in comparison. The Wendelstein 7-X stellarator is currently being built at the Greifswald branch institute, which was established in 1993, while the researchers in Garching are experimenting with the ASDEX Upgrade tokamak. The results are incorporated into JET, the European joint venture in Culham, in the UK, and in the international test reactor ITER, which has been under construction in Cadarache/southern France since 2007. If everything goes according to plan, the first power plant could go online in the middle of this century – thus igniting the fire of Prometheus on Earth once again.
In Good Hands

Developing the best possible advisory service for foreign employees and guests

As the new Officer for Integration Issues at MPS Administrative Headquarters, Katrin Sillem has been working with the institutes since mid-February on expanding the advisory service for foreign employees and guests.

MaxPlanck Research: What sparked your interest in the issue of integration and “interculturalism”?
Katrin Sillem: For one thing, I pursued cultural studies at the university. For another, before I came to the MPS, I worked for a long time in an international environment, where I learned a lot about the co-existence of different cultures.

Early this year you sent a questionnaire on the subject of “Advising and integrating foreign employees” to all institutes. How do you rate the survey results in general?
Katrin Sillem: To start with, I am very satisfied with the response rate, as almost 100 percent of the questionnaires were returned. This is an indication of how seriously the issue is taken at the institutes. The survey revealed that roughly one-third of the institutes employ full-time visitor advisors. In around two-thirds of the institutes, this function is performed on a decentralized basis, which means that, in many cases, institute employees look after our foreign employees and guests. This group in particular expressed a strong desire for greater professionalization of the role. Our aim would be to have full-time visitor advisor positions at these institutes, too. A small number of Max Planck institutes already have “International Offices.”

What issues or tasks did the institutes consider to be particularly urgent? What specific measures have you developed based on this information?
Katrin Sillem: In addition to increasing the number of visitor advisor positions, there was also a specific request for more intercultural training. We will be expanding the range of training courses in this area accordingly. As an additional urgent requirement, many institutes also suggested that we have a manual in which foreign scientists and guests can find all types of useful information on such topics as residence permits, childcare facilities, the media, etc. – an A to Z of life in Germany, as it were. We are currently in the process of preparing such a manual. It should be available in hard copy and electronic form by fall.

Financing integration activities is quite a tricky issue as, to date, no resources have been budgeted for the necessary expenditure. We are making every effort to find a long-term solution that will allow us to continue to expand our activities. If nothing else, it is important for the institutes to have a main contact person who is familiar with the legal issues surrounding, for example, visas, or who is available to act in an advisory capacity if there are problems with local authorities. This service existed before I took up my position and it will, of course, continue to be available in the future. Another idea would be to organize regional Welcome Days, which several institutes could coordinate together.

How would you describe the general goals of your work?
Katrin Sillem: I would like to increase awareness of the fact that intercultural competence should be considered a crucial, rather than a supplementary basic qualification in the MPS. The MPS took its first visible step in achieving this objective by signing the Diversity Charter in March.

In addition, we are constantly increasing our efforts to attract outstanding foreign scientists. When deciding in favor of or against a research facility, it is no longer just the scientific environment, but also the support provided for the individual researcher and his or her family that is a major consideration. The competition from universities and non-university research facilities cannot be underestimated. It thus seems to me to be extremely important that we provide a level of support that not only involves the handling of all administrative issues, but also includes activities that foster integration. This will help us attract foreign scientists and guests and ensure that they feel at home with us. They can then pursue their research work with fewer worries and, in a best case scenario, promote the MPS in their home country as an employer that cares.

MPS Signs Diversity Charter

An environment that cultivates acceptance and mutual trust, where employees are shown appreciation – regardless of gender, race, nationality, ethnic origin, religion or worldview, physical ability, age, sexual orientation and identity – in short, one that embraces and harnesses diversity: this is what the MPS has committed to by signing the Diversity Charter. Launched in 2006 by a number of German companies, the Charter has Federal Chancellor Angela Merkel as its patron. Minister of State Maria Böhmer, Federal Government Commissioner for Migration, Refugees and Integration, presented MPS Secretary General Barbara Bludau with the certificate of signature at a ceremony in Munich’s Haus der Bayerischen
Sometimes it’s not so much the intellectual issues that pose problems for scientists. For many of them, especially when spending time abroad, the first priority is to find a suitable home for the family or a good kindergarten. Visiting scientists at German universities and Max Planck Institutes receive help in matters like these from the International Centers (IBZs) and Guest Houses. Representatives of these organizations met in Munich in December to exchange ideas.

This was their fourth meeting since 2002, and it prompted considerable interest. Some 28 IBZs and Guest Houses were represented, even though there has so far been little networking between them. So when the participants met for a Bavarian sausage breakfast, they were not short of things to talk about. Items on the agenda ranged from integrating different cultures to financing and administrative matters, through to “meet-and-greet lounges” and operating instructions for washing machines in Chinese.

The IBZs and Guest Houses can trace their history back to the 1960s when the first Guest Houses – already a common feature in the Anglo-Saxon countries – were established in Germany. The next stage saw the establishment of the IBZs, with the buildings initially financed by the Alexander von Humboldt Foundation. Over time, a variety of different forms of financing have developed, and the system of organization is by no means standardized. The bandwidth ranges from autonomous associations to university endowments. At a local level, the IBZs have strong links with one another. The Munich association, for example, combines the universities and the Max Planck Society.

The IBZs and Guest Houses are united by an underlying sense of purpose that one representative from Berlin described as the “philosophy of academic coexistence.” The goal is for scientists from abroad to feel at home in Germany. On the one hand, this means finding suitable accommodation without undue difficulty. On the other hand, many visitors feel the need for personal contacts in a foreign land. Therefore, the Centers offer scientific lectures, discussion groups, concert evenings and other leisure encounters. One is even affiliated with a kindergarten and a school.

Due to the different ways in which they are organized, however, the Centers often find themselves dealing with problems on their own. Audit offices, for instance, dispute whether operating a guest house should even be one of the tasks of a scientific institution. Some participants were concerned that as funds become scarcer in the coming years, these problems will intensify. And yet, in an age of increasing globalization, paralleled by a growing skepticism toward foreigners, the IBZs and Guest Houses are now more important than ever. In order to present a more united front in the future, the representatives attending the meeting agreed to reinforce their “brand” by forming an alliance.

The meeting was also an opportunity to exchange practical experiences. On a guided tour of the newly renovated Munich IBZ, the female participants – the IBZs are mostly operated by women – drew inspiration from the interior design features. With utility costs included in the rents charged by most Centers, it is often a challenge to persuade residents to be economical in their use of electricity and water.

Working at the IBZs and Guest Houses also requires extensive interpersonal skills to strengthen communal life. The atmosphere is also aided by the requirement written into the rental agreements for residents to give presentations of their own work. The participants from Munich in particular were concerned that intercultural exchanges at the IBZs might suffer from being too dependent on the work of volunteer program planners – one reason being that many of the female scientists who previously gave generously of their time now have professional commitments of their own.
Science Guided by Ethics

Max Planck President Peter Gruss comments on the new rules for dealing with scientific risk as adopted by the Max Planck Society’s Senate in 2010

Science is of central importance to all areas of modern life, and scientific discoveries form the basis of our entire modern living environment. Therefore, we often – rightly – say that we live in a “scientific society.” Science and research are essential drivers for growth in forward-looking economies. At the same time, they are fundamental to our cultural wellbeing. Yet we also live in a “risk society” – and that applies to science, too.

The scientific community must know how to deal with risk, as scientific findings can be misused when they end up in the wrong hands, for instance with computer hackers and dictators, or even art forgers. Those who wish to develop a defense against bioterrorism attacks must understand the technologies available to the attacker. When conducting materials research and research into nanotechnology in the area of defense and weapons technology, we run the risk of developing offensive weapons. Those who investigate molecular plant genetics must also bear in mind the possibility of using seeds for biological attacks.

However, to claim that the risk of misconduct is limited to the natural sciences would be to miss the mark. Scientists who deal with issues in witness psychology must anticipate the use of their results on innocent persons. New techniques for tracing booby traps may just find use at airports – and misuse by dictators. Sociological research may violate the rights to privacy and data protection of test persons.

Research results may be used, but of course they may also be misused. We therefore speak of “dual use,” which means that there must be rules for how to handle research topics that may be misused. At the same time, research (especially basic research) hinges on scientific freedom – a freedom that is unequivocally protected in Germany’s Basic Law, art. 5, para. 3. Only scientists who are free to exchange ideas and publish their findings can become competitive internationally. In contrast, scientific freedom must be limited in cases where a scientist violates ethical rules or where science is misused to create biological weapons, computer viruses or unethical interrogation techniques, or for terrorism or military purposes.

In this context, the Max Planck Society considers it particularly important to formulate unambiguous rules that serve as guidelines for responsible scientific practice with regard to scientific freedom and risk, without running the risk of over-regulating. In March this year, the Senate of the Max Planck Society thus adopted the “Max Planck Society Instructions and Rules on the Responsible Use of Scientific Freedom and Dealing with Scientific Risk.” The rules are meant to help scientists become more sensitive to possible cases of misconduct, even – and especially – in cases where it is not obvious, and to facilitate action by scientists in critical matters of conscience.

The instructions amend the existing “Rules of Good Scientific Practice” in the Max Planck Society.

With this, the MPS is taking up an issue that has recently increasingly attracted public and political attention. In 2007, the German federal cabinet introduced a research program for civil security, with initial funding lasting through 2010. The aim of the program is to address, through intelligent security research, the increasing dangers that can originate especially in natural disasters – but it is not entirely uncontroversial in the political landscape. The German program is operated in the context of European security research. The European Union also launched its first research program for civil security from 2007 to 2013.

In this context the Max Planck Society guidelines seek to sensitize scientists at the individual level to any risks when planning and conducting research and collaborating with colleagues, and also to support them as far as possible in case of doubt or questions. The general underlying principle of the guidelines is that: “The research conducted by the Max Planck Society shall serve to gain knowledge and shall be committed to the good of humanity and the protection of the environment. Scientists must therefore avoid or minimize direct and indirect damage to people and the environment, to the greatest possible extent.”

This means that scientists must calculate the risk associated with their research in the event of misconduct, and weigh the principle of scientific freedom and transparency against any dangers. To reduce risk, every scientist must take the appropriate security measures. This might mean providing special protection for particularly dangerous materials in the laboratory, choosing cooperation partners from politically sensitive states more carefully or refraining from publishing findings – or in extreme cases, from conducting unjustifiable research.

In the Max Planck Society, the newly established Compliance Office and the Legal Department at Administrative Headquarters in Munich will help with questions about the legal constraints on research. For questions concerning ethical boundaries, any scientist is free to contact the three permanent members of the MPS Ethics Commission. If the Ethics Commission becomes involved, it may request opinions from the Director of the institute and the staff, as well as from the Scientific Advisory Board of the institute in question.

With these new rules and procedures, the Max Planck Society is deliberately drawing on the lessons from the research of its precursor organization, the Kaiser Wilhelm Society, which, primarily during the National Socialist era, ignored ethical boundaries. The legacy of the Kaiser Wilhelm Society is thus a great source of motivation for the Max Planck Society to consider the possible misuse of scientific findings early on, and to tackle it as effectively as possible.
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