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Max Planck RESEARCH
The Science Magazine of the Max Planck Society

NANOTECHNOLOGY
Peering into the Unseen

QUANTUM OPTICS
Physics Has a Core Problem

GLYCOMICS
More than Just Sweet

ART HISTORY
The Body According to Leonardo

GEOSCIENCES
The Intertwined Earth
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Galapagos – the name has a magical ring to it, and not just for biologists. A unique flora and fauna developed on this group of islands located some 1,000 kilometers off the coast of Ecuador. When Charles Darwin reached the archipelago in 1835, it was, besides the finches, above all the sub-species of giant tortoises, each specifically adapted to the ecological conditions of their individual island, that inspired his thoughts on the origin of species. But even then, many sub-species were already extinct: their ability to go for very long periods without food and water made the tortoises ideal provisions for seafarers. Today, there are still ten sub-species living on six of the islands. They are endangered primarily by non-native species, such as rats and goats, and human encroachment on their habitat.

The portly animals, which can weigh up to 300 kilograms, feed on shrubs, leaves and grasses, depending on the kind of vegetation available on their home island. Some tortoises undertake long voyages between the lowlands and the higher areas on the volcanic slopes, which are lush with vegetation even in the dry season; others spend the whole year in the lowlands, which can sometimes be very dry. To learn more about these migrations, scientists working with Stephen Blake from the Max Planck Institute for Ornithology attach GPS loggers and ultramodern 3-D accelerometers to the shells of some of the tortoises. This allows them to precisely track the animals over long periods and compare their observations with climate and vegetation data. Their findings were surprising: it is primarily adult males that walk up to ten kilometers in search of fresh, succulent food. But the researchers are still puzzled as to why the giant tortoises, which can go for months without eating, undertake these strenuous journeys.
The Intertwined Earth

When the Air Turns the Oceans Sour

Human society has begun an ominous large-scale experiment, the consequences of which will not be foreseeable for some time yet. Massive emissions of man-made carbon dioxide are heating up the Earth. But that’s not all: the increased concentration of this greenhouse gas in the atmosphere is also acidifying the oceans. Scientists at the Max Planck Institute for Meteorology in Hamburg are researching the consequences this could have.

Tracing the Noxious Five

For many years now, a phenomenon that threatens both humans and the environment has been moving to the center of attention: the “noxious five” – nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide and particulate matter. Researchers at the Max Planck Institute for Chemistry in Mainz are studying these substances with a view to clarifying the large-scale atmospheric processes associated with the bad air.

Earth’s Breath

The amounts of carbon dioxide and other trace gases that vegetation and soil exchange with the atmosphere affect the climate in a variety of ways. Scientists at the Max Planck Institute for Biogeochemistry in Jena are analyzing this complex structure – with the aid of a global network of measuring stations and new data analysis methods.

ON THE COVER: The Earth is a perfect ecosystem and the best place in the universe that we know of for life. The complex interaction of the elements earth, water and air – land masses, oceans and atmosphere – is finely balanced and works very smoothly. But the delicate interplay can easily tip. Researchers are only gradually tracking down the factors that upset the balance of our interwoven planet.
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What connects Oviedo, the capital of the Autonomous Region of Asturias in northern Spain, with the future of the German science system? Such a link, though anything but inevitable, is currently emerging: it is in Oviedo that, this fall, the Max Planck Society will receive an award for its commitment to international cooperation. In the past, the Prince of Asturias Award, sometimes referred to as the Spanish Nobel Prize, has been presented to such renowned organizations as the International Red Cross and Red Crescent, and the World Health Organization. One may well be surprised to find a German research organization mentioned in the same breath as institutions that, by their very name, are destined to play an international role. And yet this honor wonderfully reflects the equally international orientation of the Max Planck Society.

Internationalism is integral to our mission. Research at the cutting edge can be successfully marshaled only if research institutions – in this case our Max Planck institutes – are able to attract outstandingly talented junior and elite scientists from across the world, and if conditions are created that allow these researchers adequate scope to unleash their creativity. However, it isn’t our intention to simply bring the “finest minds” here to our own country – we are also a partner in numerous international research networks. And this is precisely where the Prince of Asturias Award touches on the debate surrounding the German system. The competition between knowledge-based economies is becoming fiercer, and Germany must meet this challenge if it is to sustain and expand its leading position as a center of research and innovation, and thus maintain and grow the basis of its prosperity. Over 90 percent of the global fund of knowledge is mined beyond our borders; almost two-thirds of all the publications that emerge from the Max Planck Society are the result of international cooperation. This clearly illustrates the huge importance of participating in cross-border innovation networks. Our structures, particularly in cutting-edge research, must take account of this; the process of internationalization must be pursued both internally and externally. The discussion regarding the future development of Germany’s science system must thus not be conducted solely from a national research policy perspective – that would fall far too short of the mark.

Our science system is characterized by a diverse structure of universities and non-university organizations, R&D companies and research sponsors, etc. Within this structure, we have succeeded in endowing each of the non-university organizations with a mission of their own: the Helmholtz Association, for example, is tasked with putting in place scientific infrastructures for all parties via programmed research; Fraunhofer bridges the gap between science and industry; while the Max Planck...
Society pursues research at the cutting edge. As the German Science Council right-ly comments in its recommendations pub-
lished in July, a “fundamental reform of the system” is unnecessary, since the function-
al and institutional diversity constitutes a “strength that it is essential to preserve.”

This diverse, multifaceted system is in-deed greater than the sum of its parts. It
may be compared with an ecosystem whose ability to provide water and raw materials is profoundly dependent on the extent of its biological diversity. It is the differences between functional groups that ensure that, as their number increases, the available resources are used more effectively and the system becomes ever more productive. Translated to the science system, this means that scientific value can be added to the system only as a whole through cooperation between mutually complementary participants, each with a profile of their own. It is therefore all the more surprising that the Science Council should recommend that, in the future, the universities should be elevated to the role of central organizers. I beg to differ: a university cannot organize the Max Planck Society, any more than Max Planck research projects can be developed locally inside the heads of university rectors. If we are to continue to pursue our aspirations toward cutting-edge research, we must be free to choose our own subjects and locations.

Nevertheless, a functional partnership exists, lives and breathes! For example, 70 percent of the excellence clusters to suc-
cessfully emerge from the Excellence Ini-
tiative involve Max Planck institutes; 80 percent of our Directors are also universi-
ty professors. And of course, over the past two years, the Max Planck Society has made numerous contributions to the de-
bate about the future of the science sys-
tem, while internally, our committees have discussed the central issues of science pol-
icy in great depth. The development in profile and differentiation that the Science Council is keen to see in the university sec-
tor correlates with the proposal put for-
ward in our recent position paper to estab-
lish centers of excellence and profile. Encouraging particular locations to adopt distinctive features does not by any means imply that existing research or teaching concentrations should be of lower priority or less deserving of support. Let me em-
phazise: We need a living, breathing sys-
tem in which the good rise to the top. It will be a question of fine minds. If one or two outstanding scientists can be recruit-
ed in a given field, the way is open for pio-
neering achievement. The system must al-
low for interaction.

However, I perceive a lack of instru-
ments to ensure that, within the frame-
work of the Science Council’s proposed fu-
ture pact, the participants do indeed con-
tinue to sharpen their profile as they need to. We must take care to maintain
and develop the conditions that are con-
ductive to scientific competition and ef-
fective institutional governance. For all the dynamism and internationally ac-
knowledged strength of the German sci-
ence system, developments in recent years have shown that processes in this field are not always science-led. Not every joint venture is structured to prioritize scientific effectiveness, and not every action is a product of verifiable scientific logic. With this in mind, I would welcome an indepen-
dent system evaluation. This, in my opin-
ion, would be a necessary complement to
the development now flagged by the Sci-
cence Council. The DFG/MPS system evalu-
ation conducted in 1999 showed how such a well-founded external examination can add important momentum. One of the re-
sulting proposals was, within the context of our mission, to specifically extend our cooperation with universities.

With more than 60 International Max Planck Research Schools now successfully established in cooperation with universi-
ties, consideration might be given, for ex-
ample, to replicating within Germany the highly successful model of the interna-
tional Max Planck Centers now being op-
erated as joint platforms in cooperation with world-leading research institutions such as Princeton in the USA and the Riken Institute in Japan. This would involve at least one Max Planck institute, one German university, one partner abroad, and perhaps others, merging in a subject-spe-
cific joint venture. In this way, the Max Planck Society could open the door to re-
search networks linking the world’s best scientists – and thus fulfill anew its role in the German science system.

PETER GRUSS
President of the Max Planck Society
Max Planck Center Established in Tokyo

The Max Planck Society and the University of Tokyo intend to intensify their work in the new field of integrative infection research and improve their network links still further. The joint Max Planck Center of Integrative Inflammology will bring together the research projects being undertaken by both organizations and simplify the exchange of ideas and experience between disciplines. “Inflammology research will be one of the central issues in the field of medicine in years to come,” commented the President of the Max Planck Society, Peter Gruss. The purpose of the body’s inflammatory reactions is to protect against the harmful effects of pathogens, degenerative cells, etc. However, the response is effective only if it is precisely regulated and not excessive. Otherwise, such defensive reactions can do more harm than good. Chronic inflammation, in particular, can lead to tissue damage, which in turn can aggravate existing conditions or even trigger new ones. In establishing the new center, the Max Planck Society is continuing to develop its close relations with research organizations in Asia and Japan. Initially located on the campus of the University of Tokyo for a period of five years, the new center is headed by Rudolf Grosschedl of the Max Planck Institute of Immunobiology and Epigenetics in Freiburg together with Tadatsugu Taniguchi of Tokyo University. The scientists involved will also benefit from the proximity of the university clinic, with which the center is expected to cooperate closely.

Max Planck Society Receives Prince of Asturias Award

It is an award that honors the Society as a whole – and it came as something of a surprise: After the award went to the International Red Cross and Red Crescent in 2012, this year, the Prince of Asturias Foundation elected to reward the Max Planck Society for its commitment to international cooperation. Announcing its decision, the jury praised “the Society’s European orientation, interdisciplinary approach and close cooperation between Max Planck institutes and other research institutions and universities the world over.” In addition to the MPS’s scientific excellence, the jury also emphasized our international support for junior scientists in the form of over 40 Partner Groups worldwide that enable highly qualified young researchers to develop research groups of their own in their home countries. The President of the Max Planck Society, Peter Gruss, was delighted at this recognition: “This award is a remarkable honor that recognizes the work of all Max Planck Researchers and their partners worldwide.” The award will be presented by the Spanish Crown Prince on October 25 in Oviedo, the capital of the Principality of Asturias.
Martin Stratmann Succeeds Peter Gruss as President

At its meeting on the periphery of the annual assembly in Potsdam, the Senate of the Max Planck Society elected current Vice President Martin Stratmann as President for the term of office from 2014 to 2020. The 59-year-old chemist is Director at the Max-Planck-Institut für Eisenforschung GmbH in Düsseldorf. He takes over from Peter Gruss at the 65th General Meeting of the Max Planck Society in Munich in June 2014. The evening Plenary Assembly at this year’s meeting, which was dedicated entirely to internationalization, was addressed for the first time by Anne Glover, scientific advisor to EU Commission President José Manuel Barroso. As a molecular biologist herself, she argued that “science should have a strong voice in Europe” and praised the courage displayed by the German government in increasing its investment in research and development in times of crisis. Federal Research Minister Johanna Wanka paid tribute to the Max Planck Society’s initiatives aimed at expanding its global network, and in particular to the commitment of the current President. He, in turn, stressed that, alongside the Fraunhofer-Gesellschaft, the Max Planck Society is one of Germany’s very few internationally recognized science brands: “We aim to strengthen our Max Planck brand name, not just in Germany, but above all internationally, by pursuing research of the highest quality and heightening our international presence. Where we succeed, Germany profits too,” declared Peter Gruss.

Max Planck Research Prize 2013 Goes to Chris Field and Markus Reichstein

Chris Field and Markus Reichstein received the Max Planck Research Prize 2013 in recognition of their research into the effects of climate change on ecosystems. Chris Field is Founding Director of the Department of Global Ecology at the Carnegie Institution and a professor at Stanford University; Markus Reichstein is Director at the Max Planck Institute for Biogeochemistry in Jena. The prize winners each receive 750,000 euros to fund their research and, in particular, to finance cooperation with scientists in Germany and abroad. The Max Planck Research Prize is one of Germany’s most valuable science awards. Financed by the Federal Ministry of Education and Research, the prize is presented annually by the Alexander von Humboldt Foundation and the Max Planck Society to two scientists, one working in Germany and the other working abroad. Markus Reichstein and Chris Field received the prize for their definitive work in broadening our understanding of how life on Earth is responding to climate change and the interactions to be expected between the biosphere and the atmosphere. Not only are their fundamental findings pioneering importance, but they are also helping to gauge the consequences of climate change for mankind.
“Yet another man”

Biologist Julia Schröder on the lack of visibility of women at conferences

Why does it feel as though women are under-represented at conferences? At the 2011 conference of the European Society for Evolutionary Biology (ESEB), Julia Schröder of the Max Planck Institute for Ornithology was not the only one who felt there were too many men. Together with colleague Hannah Dugdale (University of Sheffield), she has been studying the figures for female participation over the past ten years.

How did you arrive at the idea of investigating the number of women?

Julia Schröder: It was quite amusing; I was invited to a presentation at the ESEB conference, and as the next speaker stepped up, I suddenly heard a woman behind me groan, “Yet another man.” I had to laugh, because I had thought the same thing myself. It was all men, to the point that it became a running gag. We began to count men and women, and when we met in our groups for lunch or dinner, there was only one topic of conversation. On the way home, I went through the conference program and decided, together with Hannah Dugdale, that we should write a paper.

Had you already decided where you were going to publish the article?

No, we originally intended to write something for the ESEB newsletter or website, but then we began to think about a statistical analysis. There was hardly any such work to date. Most articles simply contain a verbal description of the visibility of men and women. It was important to us to know that our results would be evaluated by peer review – hence the publication in the Journal of Evolutionary Biology.

You have done a great deal of work, and – as the 38 names on the list of authors shows – brought in a great deal of expertise. What, exactly, did you find?

Well, first, that our gut feeling didn’t deceive us. We identified how many women had appeared as “invited speaker,” “plenary speaker” or “oral presenter,” how many had been invited, and tracked the figures back to 2001. At the same time, we also considered these figures in relation to the number of women on various rungs of the career ladder in the scientific community, while taking into account the composition of organizing committees and the gender ratio among lead authors and last-named authors of current publications. These, after all, are the ones who are invited as a matter of preference, because science has been advanced by their findings.

To summarize, it’s fair to say that men and women were more or less equally represented in the case of poster presentations or “regular talks.” But measured against the gender ratio on the corresponding rung of the career ladder in the scientific community, there ought to have been far more female scientists among the “invited speakers.” That isn’t in any way intended as a criticism of the ESEB organizers. But it does mean that an element of high-quality science is being lost, to the detriment of progress in evolutionary biology.

Why is that?

Women are less likely than men to accept invitations to appear as “invited speakers.” There was a marked gap between the number of female scientists invited and the number who actually attended, a gap that wasn’t in evidence among men.

Perhaps women have no desire to attend male-dominated conferences?

I think it’s more likely that women with children find it difficult to juggle their time. The time of life when you think about having a family often clashes with the stage in your career when it is particularly important to be in attendance to discuss your own research findings and build up networks with scientific colleagues, both male and female. Men are usually more flexible. Their role as fathers rarely keeps them home for long.

But that’s just a supposition?

Yes. The next step is to find out whether this really is the reason why conference invitations are turned down. It’s probably at least one factor, which triggers a downward spiral, as it were. Careers suffer from lower visibility and fewer opportunities for networking, meaning there is less chance of grants and prizes. And fewer women in top positions means fewer female role models for female students making their way into science.

So it’s always the same women who play an active part in committees?

Precisely. Until at some point their workload becomes so great that they, too, have to say no. Quite apart from the fact that many women get tired of being role models just because they are mothers. A lot of blog entries have shown just that in England, where our study has found a wide audience.

Do you sympathize with this attitude?

Of course, each of us must find our own way. It also shows that not all of the strategies employed are productive. Childcare at the conference venue is a nice idea, but children have to go to school. And even paid, professional and individual childcare at home can’t cope with every need when the activities of three children require the full-time commitment of both parents.

And how about yourself: Will you be attending the ESEB conference in 2013?

I will be taking part. But only because it’s being held in Europe again and my husband is looking after our children. As a theoretical biologist, he can also work from home. We did consider going to Portugal, all five of us, and having a holiday after the conference. But that would cost an awful lot, and is against the business travel regulations.

Interview: Susanne Beer
The Physics of Waves

Leverkusen was the setting for the awards ceremony at the climax of the 48th national Jugend forscht contest to find Germany’s top young researchers. All of the awards in the physics category are funded by the Max Planck Society – from the regional and state contests through to the national finals. The national award in the physics category went to 18-year-old Daniel Pflüger of Lüneburg. He used lasers and digital cameras to investigate the complex waves that are created when a droplet falls on the surface of a body of water. To visualize the process, scientists generally use high-speed cameras. But these are expensive, so Daniel Pflüger came up with a more economical process. Rather than directly record the droplet’s moment of impact, his method analyzes the resulting waves. He was able to go some way toward measuring the complex reaction of the water following the impact of the droplet by using lasers and digital cameras to precisely measure the height of the resulting waves. The jury was particularly impressed by the combination of theory and practice. “The complex theoretical calculations were elegantly resolved with the same skill with which the idea was put into practice,” remarked Ferdi Schüth, Director at the Max-Planck-Institut für Kohlenforschung (Coal Research), in praise of the winner.

This year’s winner of the national prize for physics, Daniel Pflüger (right), accepts the award from Ferdi Schüth, Director at the Max Planck Institut für Kohlenforschung (Coal Research) in Mülheim an der Ruhr.

Science in Pictures

At the 2012 Lindau Meeting of Nobel Laureates, Munich-based photographer Volker Steger invited the Nobel Prize winners to a photo shoot. He first asked them to outline their research using wax crayons on a sheet of white paper before photographing some of the laureates, including Paul Crutzen, Gerhard Ertl and Theodor Hänsch, with their sketches. These pleasing portraits of scientists were on display until August 25 as part of the Sketches of Science exhibition on the island of Mainau. The process by which the images were created is described on the website and the photo series is available for download in PDF format at: www.lindau-nobel.org

Bohemian Gravity

McGill University graduate Tim Blais has briefly swapped theoretical physics for music. His parody of Queen’s number one hit “Bohemian Rhapsody”, an “A Capella Science” song about string theory, is currently rocking the internet. Turn it up and make sure to sing along: “Is it real? Or is it just fantasy?” There’s even an Einstein sock puppet joining the chorus! www.youtube.com/user/acapellascience

The History of Pop

In his PopHistory blog, Bodo Mrozek traces the development of pop culture since 1945. “I try to directly juxtapose differing national perspectives, such as Anglo-American pop cultural studies, French histoire sociale du rock and German pop history,” explains the scientist, who works at the Max Planck Institute for Human Development. Items include reviews, notes on new releases, events and conference reports – a sophisticated mix with an appeal that reaches beyond music researchers: www.pophistory.hypotheses.org/author/pophistory

Applications Made Easy

No, you can’t apply to the Max Planck Society in general, as an institution – nor is there such a thing as a deadline for general applications. The Max Planck system is not so easy to navigate for many would-be young scientists. A brief how-to video is now available to help them on their way, and will hopefully stem the flow of e-mails. It explains, in a light-hearted way, where applicants should look for information, whom to contact and how to link up with other doctoral students: www.youtube.com/maxplancksociety

On the Net

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Peering into the Unseen

When new technologies literally touch us, the general discussion about their opportunities and risks becomes more intense. Nanotechnology applications in medicine, nutrition and cosmetics, for example, are particular subjects of public debate. Our authors have observed that there’s a lot more to these debates than just scientific facts.

TEXT WOLFGANG M. HECKL AND MARC-DENIS WEITZE

Structures about 10,000 times smaller than the diameter of a human hair – that is the order of magnitude for research in nanotechnology, where the typical unit of measurement is the nanometer, one millionth of a millimeter. Nanoscience – the name derives from the Greek word nános (dwarf) – promises us new materials, surfaces with customized properties, and machines the size of a molecule. The societal issues it raises are as fundamental as the prospects are revolutionary. The questions have no right or wrong answers.

Following years of intense and – particularly in Germany – extremely successful research, we find ourselves now in a phase when these new nanoproducts are coming onto the market. Actually, there are already several hundred items that contain nanoparticles, particles no more than millionths of a millimeter in size. Tennis rackets and golf clubs are made more stable by nanoadditives in the plastics, sunscreen with nanoparticles of titanium dioxide offers particularly effective UV protection, nanoparticles of silver have an antibacterial effect in textiles and food-stuffs stay fresh longer thanks to nanopackaging. Printer toner and colloids, both of which are “nano,” have existed for years.

“Nano” can also describe the existence of particular capabilities that arise due to particular properties of matter on the scale of atoms and molecules. This applies both to inanimate objects and to living systems. The growing understanding of nanosystems is now being applied for the first time in the complex area of self-organizing, living systems, and thus also in nanomedicine.

The potential is as great as the unknowns. Nanoparticles have specific strengths, but they conceal unfamiliar risks, as well. Nanomedicine entertains visions of tiny transport capsules intended to accurately deposit medications in the body, but there are reservations about what happens to the nanoparticles after they have done their work. The tiny particles are able to penetrate cell membranes, and may become concentrated in organs, or provoke inflammations in the respiratory tract.

Nano-objects have always existed, long before the name came into being. In fact, all medicines are, in principle, nano-based if they address the molecular
Helpers in the nanosphere:
Nanoparticles (gray) prevent cotton fibers from becoming wet or soiled.
causes of diseases. The molecular interaction of antigens and antibodies – the energies exchanged and the forces between them – is medical nanotechnology and is instrumental in the development of treatments, for example. Drug delivery systems may clear the way to personalized medicine.

Another field with high expectations is nanobased cancer therapy. The hopes and expectations are especially high here. As an example, nanoscale systems have been developed in recent years that effectively distribute active pharmaceutical agents in the body and deliver them to the correct locations. A nanoparticle cancer therapy from German company MagForce, for instance, has reached the approval stage for certain restricted indications. And there are already medications contained in lipid vesicles. Nanoparticles based on polysaccharides or polymers can also serve as carriers. Ideally, the active agent not only reaches the right place in this manner, but is also released at a specified time, as well.

Scientists are hopeful that, in the future, greater molecular knowledge and understanding of the causes of diseases will bring many benefits, including better chances of recovery for damaged tissue, in that nanomaterials and adult stem cells will be employed to synthesize new skin, new bones, nerves and new blood vessels. Self-organizing behavior will also one day be utilized in nanomedicine, for example once we better understand the process by which wounds heal.

In addition to therapy, nanoresearch will also lead to advances in diagnostics, such as in the area of imaging procedures. Supermolecular systems are already being routinely employed in X-ray and NMR diagnostics today. Nanoscale diagnostic units should facilitate simple and fast medical examinations. DNA- and RNA-based biosensors for nucleic acids and proteins are conceivable, as is information processing with DNA-based reagent networks for analyzing complex mixtures of biological molecules. Nanomaterials and nanosurfaces offer new avenues for implants and prosthetics.

“Drugs with no side effects, cures for cancer and cardiovascular diseases, long-lasting implants for bones and teeth or for stimulating neural activity all promise a healthy future and sound almost too idealistic to be true,” says risk researcher Antje Grobe in Stuttgart. Nanomachinery and nanorobots that operate in the bloodstream, for instance, are currently still a dream of the future, but they have particularly caught the public’s imagination.

Balanced information and communication about the methods, uses and risks of nanomedicine are essential – not least to clearly separate fact from fiction. Nanomedicine certainly won’t transform us into superhumans, but it may one day revolutionize the above-mentioned drug delivery systems if drugs – packaged in nanoparticles – can selectively target cells at the desired treatment location by recognizing surface characteristics.

The word “nano” has served as an effective term in garnering political funding for research, but certainly a more exact definition is needed when it comes to matters of product classification and consumer protection. Yet this is not as easy as it might seem. Should nanoparticles be defined solely by their dimensions, or is their function and reactivity more relevant, for instance for toxicological testing? Are the usual quantitative definitions of threshold values sufficient for “nano”, based on the maxim that “the dose makes the poison”? Or do we have to apply the number of particles and their surface areas in addition to their bulk quantity as the relevant gauge, since these dimensions determine reactivity?

The EU Commission presented a suggested definition for nanomaterial in October 2011: a nanomaterial is “a natural, incidental or manufactured material containing particles in an unbound state, as an aggregate or as an agglomerate, and where, for 50 percent or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm to 100 nm. [...] In deviation [...], fullerenes, graphene flakes and single-wall carbon nanotubes with one or more external dimen-
sions below 1 nm shall be considered to be nano-materials.”

That sounds plausible initially, but it offers various points for criticism. This definition renders all particles of a certain dimension generally suspicious. A sharp limit such as 100 nanometers is arbitrary. Why not 30 or 500 nanometers? Wouldn’t it be more reasonable to develop a catalog of risk-relevant material properties?

Such questions of definition may appear to be abstract at first glance, but they aren’t abstract in the least! There is, for instance, a new EU-wide cosmetics regulation coming into force this year, according to which all components in the form of nanomaterials must be clearly listed in the ingredients. “The Cosmetics Regulation requires labeling of nanomaterials (name of the ingredient, followed by ‘nano’ in brackets) in the ingredients list,” to quote from this paper.

More than half of all Europeans haven’t yet heard of nanotechnology. And although the situation is better in Germany, even here, more than a third of the population has no concept of nanotechnology, as shown by the latest opinion polls conducted by the EU’s Eurobarometer. Even so, it can be seen in Germany that the attitude of the majority of consumers continues to be positive – even if the increasing level of knowledge is causing growing differentiation in people’s opinions, depending on the field of application. The proportion of those having difficulty reaching an overall opinion is considerable.

So how will public opinion evolve? Relevant studies continually show that more information doesn’t automatically create more approval, but rather tends to polarize the existing positive or negative attitudes. Studies of this nature also make it clear time and again that how people relate to nanotechnology depends on many different factors. Communication can hardly dispel what doubts there are, since they derive from people’s fundamental anxieties and attitudes. And these, in turn, have proven to be remarkably stable over time.

There have already been several waves of media attention whose starting point was not so much the concrete hazards, but the opinions and position papers complaining about these hazards. For example, a background paper entitled “Nanotechnology for Mankind and the Environment” (Nanotechnik für Mensch und Umwelt) published by Germany’s Federal Environment Agency (Umweltbundesamt, UBA) in October 2009 was interpreted by many in the media as a warning about nanotechnology. For example, the front page of the Süddeutsche Zeitung on October 21, 2009, as well as Spiegel Online proclaimed: “Ger-

The situation is growing more and more confused with the increasing number of studies produced
ences and Humanities – to take a look at the applications that directly affect us as human beings: nanotechnologies in medicine, cosmetics and nutrition literally touch the consumer.

Many questions about opportunities, risks and solutions to problems arise at this point. What can we expect from nanomedicine? What effects do nanomaterials in cosmetics have? How does “nano” taste – and is it healthy? Will we soon need to read a leaflet enclosed with consumer products, as we do now with medicines? As a result, an academy symposium was held in Munich in late 2010, with the findings recently published as a volume of essays. In addition to a presentation of the scientific and technical opportunities and challenges involved, a discussion of the communication aspects took up considerable space.

Ortwin Renn, a technology sociologist in Stuttgart, and his associate Antje Grobe identified three points during this discussion that are important for dealing constructively with nanotechnology (as with every other new technology). First, they made it clear that knowledge today is indeed ambiguous and uncertain, but in no way arbitrary. In the context of risk assessment, it is especially important to define the bandwidth of knowledge that is methodologically tenable, and to separate the absurd from the possible, the probable from the certain.

Second, Renn and Grobe emphasized that expert knowledge and lay perceptions should be categorized as mutually complementary rather than contradictory. They explained that the acceptability of risk can’t be determined by means of expert knowledge, but that reasonable expert knowledge is an absolute prerequisite to being able to reach a carefully considered judgment about acceptability. Responsible action must be measured against how objectively, adequately and morally justifiably decisions are made, considering the uncertainties. If one wants to judge risk rationally and fairly, it is, they say, essential to apply ethically justifiable evaluation criteria and standards, as well as to integrate the best available systematic knowledge.

Third, decisions about the acceptability of risks are ultimately always based on subjective considerations that incorporate people’s knowledge and values. As Renn and Grobe put it, discourse without a systematic base of knowledge is but empty talk, while discourse that ignores the moral quality of the potential actions helps immorality gain acceptance. Morality and objective expertise must both be integrated equally into the discourse on risk.

The academy symposium was held in the Centre for New Technologies (ZNT) of the Deutsches Museum – a highly appropriate location. The Nano- and Biotechnology Exhibition that opened there in 2009 offers a broad overview of this field. Certain exhibits make deeper digressions into specialized material. Multimedia stands illustrate various ways of looking at the sociopolitical issues and provide visitors with lines of reasoning with which they can find their own answers.

To directly convey the research process, the exhibition encompasses various laboratories, including a hands-on lab where visitors can conduct their own experiments. The Deutsches Museum has been presenting the scientific process live to the public in its Open Research Laboratory since 2005. Nanoresearch is now taking place in the midst of the exhibits, with doctoral students using their instruments and providing answers and explanations to museum visitors. This approach creates a completely new kind of model for young people considering a career in research, giving them the opportunity to meet young scientists.

The researchers, in turn, come to understand that communication must be a natural part of their profession. A study evaluating the Open Research Laboratory highlights the fact that this part of the exhibition is not only viewed very positively by visitors, but is also taken as a stimulus to engage further with the topic of nanotechnology.

Indeed, the innovative concept has already been exported – as Coordinator of the EU’s “NanoToTouch”
project, the Deutsches Museum has supported other science centers and museums in establishing similar Open Research Laboratories in cooperation with local university partners. This new kind of science communication is now being conducted across Europe. This interweaving of dialog and research is a direct response to the demand for more transparency and accessibility in the sciences.

How current research actually happens is being demonstrated here. “Scientists to Touch,” as it were – ready to discuss their own motivation and their own work. In addition, the event forum offers an interdisciplinary platform for lectures, conferences, discussion rounds and public dialog.

Science centers and museums are an ideal forum for these kinds of activities. They present information in a neutral environment, offering opportunities for the exchange of ideas and public discourse. That is why the Deutsches Museum has lately been employing numerous techniques in a bid to get visitors actively involved. The Centre for New Technologies makes it clear that not everything feasible is also sensible. Every one of us is called upon to help shape the future together. After all, as the Deutsches Museum sees it, future technologies develop within the context of culture, not isolated in the lab.

The purpose of the “nano” debate can’t be simply to persuade the consumer of the blessings of “nano-products.” Rather, manufacturers and communicators must highlight the genuine advantages as against the possible risks and take to heart the concerns and wishes of the consumers. Scientists are challenged to reach out to people and to permit them to share in the scientific world’s knowledge and motivation for finding answers to the future challenges of our society. With the academies and intercommunication platforms such as the Deutsches Museum, we already have a sound foundation for taking this dialog on innovation forward.

**THE AUTHORS**

**Prof. Dr. Wolfgang M. Heckl** studied physics at the Technische Universität München (TUM) and obtained his doctoral degree from there in 1988. Thereafter, he worked as a postdoc at IBM Research, and subsequently as an assistant professor at the TUM. Heckl obtained his German postdoctoral lecturing qualification in 1993 and was appointed that same year as professor of experimental physics at LMU Munich. He has been the Director General of the Deutsches Museum in Munich since 2004, and was appointed to the Oskar von Miller Chair of Scientific Communication (TUM) in 2009. Wolfgang M. Heckl advises the European Commission and the German federal government in the field of nanotechnology and science communication. He is spokesman for the Nanotechnology Topic Network of the German National Academy of Science and Engineering (acatech).

**Dr. Marc-Denis Weitze** studied chemistry, physics and philosophy. He obtained his doctoral degree in theoretical chemistry from the Technische Universität München (TUM). Following many years of involvement in the field of science communication at the Deutsches Museum, he currently works as a scientific advisor at the headquarters of acatech, responsible for activities in the areas of communication for technologies, energy, biotechnology and nanotechnology. He obtained his German postdoctoral lecturing qualification in science communication at the TUM School of Education.

**THE BOOK**

Unfavorable prognosis: According to simulations of researchers at the Max Planck Institute in Hamburg, the pH value of the oceanic surface layer will be considerably lower in 2200 than in 1950, visible in the color shift within the area shown in red (left). The oceans are becoming more acidic.
They’re called “sea butterflies” because they float in the ocean like a small winged creature. However, pteropods belong to the gastropod class of mollusks. They paddle through the water with shells as small as a baby’s fingernail, and strangely transparent skin. Though tiny, they are tremendously important because there are billions of them. Fish – whales, too – swallow them down in vast quantities. Pteropods are nautical nibbles. American zoologists simply call them the “potato chips of the sea.” But it seems that the supply of pteropods is endangered. Climate change, or more precisely, ocean acidification, may pose serious problems for them in the future.

It is common knowledge today that carbon dioxide emissions are warming the Earth like a greenhouse. Less well known is the fact that the rising concentration of carbon dioxide in the atmosphere also leads to the oceans slowly becoming more acidic. This is because the oceans absorb a large portion of the carbon dioxide from the atmosphere. Put simply, the gas forms carbonic acid in the water. The more carbon dioxide humans expel into the air, the more CO$_2$ is dissolved in water, and the more carbonic acid forms. The pH level, which indicates how alkaline or acidic the water is, falls. That becomes a problem for the pteropods and other living creatures because, at lower pH values, they can hardly generate any calcium carbonate for constructing their shells. What consequences this will have for life and the food chain in the sea is still largely unknown.

Today, the pH value of seawater is 8.1, making it, strictly speaking, a weak base rather than an acid. The term acidification applies nevertheless, because the pH value has fallen toward acidic
by a bit more than 0.1 since the start of the industrial revolution. Although 0.1 doesn’t sound like much, the pH value scales logarithmically, so it actually represents an increase in the acidity of water by about 30 percent already.

SEARCHING FOR ANSWERS WITH THE COMPUTER

When water reacts with carbon dioxide, it can be expressed in a simple chemical equation. However, the oceanic pathway of carbon dioxide and the carbon it contains is so complex that researchers haven’t yet been able to fully estimate how the oceans will change. How quickly will various regions of the ocean acidify? What effect will high levels of carbon dioxide have on the survival of phytoplankton, the microscopic algae that are the basis for all life in the oceans? Will the uptake of carbon dioxide slow down in the future? All of these questions still need to be answered.

Tatiana Ilyina is attempting to find the answers with the aid of the computer. The oceanographer works at the Max Planck Institute for Meteorology in Hamburg, where simulations of the Earth’s climate and calculations of climate change have been carried out for many years. Ilyina’s work focuses primarily on the carbon pathway from the atmosphere into the oceans, because this strongly influences climate change: by absorbing carbon dioxide from the atmosphere, the ocean reduces the greenhouse effect.

Ilyina’s specialty is simulating the biogeochemistry of the oceans. This includes the chemical processes that occur in seawater, the seafloor and between substances that marine organisms absorb and release. Carbon is an important biogeochemical component, and carbon dioxide therefore has a major impact on the biogeochemistry. Ilyina has spent a lot of time in the past few years translating biogeochemical processes into mathematical rules and incorporating them into the climate models of her colleagues, espe-
cially into the standard ocean chemistry model known as HAMOCC, which has been well established for many years now. The computer simulations have since produced several interesting insights.

Researchers like Tatiana Ilyina always try to simplify reality in their simulations, yet still include the key processes in their models. In the case of biogeochemistry, this is very challenging because carbon has many pathways. Even the transport of the carbon dioxide into the sea is complex, because how much gas dissolves in seawater, among other factors, depends, for instance, on the water temperature. Cold water absorbs more gas than warm water. The Arctic Ocean, as the simulations show, is thus likely to acidify considerably faster over the coming decades than, for example, the subtropical and tropical regions of the oceans.

**CARBON DIOXIDE WITH THE WEIGHT OF 500,000 CARS**

When carbon dioxide (CO$_2$) from the air passes into the sea, it reacts with water (H$_2$O) to form carbonic acid. This, in turn, reacts with the carbonate ions (CO$_3^{2-}$) naturally contained in water to form bicarbonate (HCO$_3^-$). Since CO$_2$ is quickly converted into ions and thus becomes unavailable for the exchange with the air above, the ocean can continuously absorb large quantities of CO$_2$. The oceans swallow a mass of CO$_2$ equivalent to the weight of 500,000 automobiles every day. The various ions are in equilibrium and can be transformed into one another when environmental conditions change. The pH value also influences this equilibrium.

Ilyina’s simulations showed that acidification shifts the equilibrium toward bicarbonate. For many sea creatures, the accompanying decline in carbonate ions may be fatal, because carbonate is an important component of mollusk and snail shells. If more and more CO$_2$ enters the oceans, the quantity of carbonate ions could decline so far that calcium carbonate production is impaired. If the amount of carbonate falls further still, shells made of calcium carbonate may even dissolve.

The findings from Ilyina’s group are also important for the upcoming report of the Intergovernmental Panel on Climate Change (IPCC). The Max Planck Institute for Meteorology in Hamburg is one of about twenty research institutions around the world whose climate simulations form the scientific basis of this report. The different simulations are so important because each of them yields slightly different results.

The experts of the Intergovernmental Panel on Climate Change (IPCC) are responsible for distilling something like a scientific consensus from these models. This international climate model comparison project is called Coupled Model Intercomparison Project Phase 5 (CMIP5). For a long time, simulations with climate models focused only on currents and temperatures. After the influence of ocean biogeochemistry was recognized, biogeochemical computations were included in CMIP5 for the first time. “Although the models differ slightly from one another, they all agree that, from a global perspective, the oceans are acidifying,” says Ilyina.

Deviations arise primarily when the various models treat individual regions – that is, when regional details become important. Simulations show that there will be winners and losers among the phytoplankton. Several calculations even predict that phytoplankton in some ocean regions, such as the Arctic, will flourish more than previously. The reason: the receding ice allows more sunlight to penetrate the water, which is exactly what plankton algae need, just like plants on land.

However, most of the simulations predict the opposite: that ocean acidification will, on the whole, bring disadvantages to these sea creatures. The mechanisms behind this are still not completely understood, but some experiments show that the growth of algae may be impaired. Accordingly, the quantity of plankton is expected to decline in the coming decades.

In addition, a physical effect could also contribute to the algae starving. The surface layer of the oceans will warm up further due to global warming. This would form a warm body of water that floats on top of the deeper, cold water. The mixing between these bodies of water will then be slower, as the boundary between warm and cold acts like a separation layer. The result is that the transport of deep, nutrient-rich water to the surface is interrupted. However, these nutrients are essential for the growth of the phytoplankton. The data from Ilyina’s research group also indicate a decline in phytoplankton.

The decline of the phytoplankton population affects not only the food chain in the oceans; it also directly affects the carbon cycle. The phytoplankton absorb large amounts of carbon dioxide and transform it into biomass. When the algae die, they sink into the deep. In this way, large amounts of CO$_2$ are ultimately withdrawn from the upper layers of the ocean and removed from the CO$_2$ exchange with the atmosphere for long periods. Climatologists
Our simulations show that the oceans’ capacity to absorb CO₂ will indeed decline in the coming years.

refer to the oceans as a carbon sink. But it will shrink if the phytoplankton concentration declines.

Physics, too, plays a role in the decrease of CO₂ being sequestered into the deep ocean. Within the relatively well mixed water of the North Atlantic today, there is strong circulation and mixing taking place, transporting large quantities of CO₂ into the deep ocean. Enhanced thermal ocean stratification could weaken this transport considerably in the future.

SULFUR COMPOUND IS A RAINMAKER

“Our simulations show that the oceans’ capacity to absorb CO₂ will indeed decline in the coming years,” says Ilyina. “Unfortunately, we don’t yet know what factors play the most critical role in this.” How great is the influence of the phytoplankton and the biological transport of CO₂ into the deep? How strong is the effect of the physical transport? What role does the equilibrium of the ions and the pH value of the water play?

Ilyina now wants to attempt to focus on individual aspects of her simulations to determine their role in the oceanic carbon cycle. The problem is this: “If we switch off certain parameters, we have to make sure that the simulation still corresponds to reality and delivers plausible results.” Tatiana Ilyina is the right person in the right place for this. Not only is she an oceanographer, but she also has many years of experience in constructing models. “I simply enjoy constructing models,” she admits. The climatologist also has the right tools for transforming complex processes involved in ocean biogeochemistry into algorithms for climate simulations.

Just how important ocean biogeochemistry is can be seen from a further experiment that Ilyina conducted in collaboration with her colleague Katharina Six: simulating the future release and transport of dimethyl sulfide gas. Anyone who has trudged through seaweed on the beaches of the Baltic knows the musty smell of this substance. It is generated when algae die and decompose. Dimethyl sulfide is one of the rainmakers. It rises high into the atmosphere above the oceans and ultimately, via several intermediate steps, contributes to the formation of clouds there. Emission of dimethyl sulfide from the ocean is the largest source of sulfur in the atmosphere.

The simulation shows that the flux of dimethyl sulfide into the atmosphere decreases due to ocean acidification. This results in fewer clouds, which reflect the Sun’s energy. Consequently, the Earth becomes warmer.

The consequences of increased CO₂ concentrations in the ocean are not yet fully understood. Researchers now refer to global warming and ocean acidification as the evil twins. The relationships become even more intricate when one considers that the carbon cycle in-
fluences other cycles in the ocean, such as the nitrogen cycle. This cycle is driven by, among other things, cyanobacteria – the phytoplankton known as blue-green algae.

Cyanobacteria have existed for hundreds of millions of years. They developed during a time when little oxygen was present in the Earth’s atmosphere, but a lot of CO$_2$. These microbes absolutely love CO$_2$. Increased CO$_2$ concentrations drive them to high levels of activity. Cyanobacteria are one of the few life forms that are able to convert gaseous N$_2$ into other nitrogen compounds, such as those that plants use for nutrition.

CONSEQUENCES OF ALKALINITY ENHANCEMENT UNFORESEEABLE

Thus, more CO$_2$ means more nitrogen compounds. No one can say with certainty yet whether that will prove advantageous or disadvantageous for life in the ocean. There is no doubt that cyanobacteria profit from the added CO$_2$ in the oceans. Mainly, however, the example shows how difficult it is to fully comprehend the biogeochemical processes and transfer them to a simulation.

This also applies to the calculations Tatiana Ilyina’s group is developing to simulate the idea of halting ocean acidification artificially. There is a natural process that serves as a model for this: Carbonate ions that are supplied in the ocean from the weathering of, for instance, limestone, aren’t accompanied by acidification of seawater, but exactly the opposite. Carbonate ions that derive from eroded rock and other alkaline ions neutralize acids, thus buffering the effect of CO$_2$. This has been happening for millions of years. For years now, the question of whether ocean acidification can be slowed down has been a topic of discussion – whether we could fertilize the oceans with additional alkaline compounds, such as calcium hydroxide, or hydrated lime.

Researchers call these methods of artificial mitigation of climate change geoengineering. Ilyina has checked whether this would be feasible at all. The results of the simulation were sobering. One would have to pour into the oceans 200 times the quantity of ions that are deposited globally by natural weathering. This would require some 70 to 100 billion tons of limestone. That is quite expensive.

Initially, though, the pH value would climb to 8.7 at the locations where the alkalinity was added to the seawater, until the currents distributed it. That would be too much of a good thing, and a massive intervention in the ecosystem. The consequences for living creatures would be unforeseeable. For this reason, Ilyina thinks that global alkalinity enhancement wouldn’t make much sense. Especially since her research makes it clear that the relationships between biogeochemistry and climate are too complex for humans to monitor and control the effects if they destabilize individual processes, such as the carbon cycle.

Simulating the future of the oceans: Tatiana Ilyina (left) and Katharina Six discuss their latest results.

TO THE POINT

- The increasing concentration of carbon dioxide in the atmosphere is not only changing the climate, it is also acidifying the oceans.
- The concentration of carbonate ions is decreasing in seawater with decreasing pH values, making it harder for all organisms with calcareous shells to construct these shells.
- Ocean acidification causes feedback that can amplify the greenhouse effect.
- Model simulations show that primary production by phytoplankton in the oceans may decline as a result of climate change, and the oceans may absorb less CO$_2$ from the atmosphere. At the same time, the oceans would release less dimethyl sulfide, impairing cloud formation and allowing more thermal radiation from the Sun to reach the Earth’s surface.
- Slowing down ocean acidification by geoengineering could be expensive and have unforeseeable consequences for biogeochemistry, the ecology of the oceans, and the climate.

GLOSSARY

CMIP5: In the Coupled Model Intercomparison Project Phase 5, climatologists are examining the results of climate simulations that were undertaken by more than twenty institutions worldwide. The conclusions will be distilled into a scientific consensus for a report to the Intergovernmental Panel on Climate Change (IPCC).

Phytoplankton: Microorganisms in the ocean, such as green, brown and blue algae, that, like plants, utilize the energy of sunlight through photosynthesis. Phytoplankton is the first link in the food chain of the oceans.
In many regions of the world, air pollution is set to worsen in the decades to come. Jos Lelieveld and his colleagues at the Max Planck Institute for Chemistry in Mainz forecast where this will happen. Their studies of atmospheric chemistry also uncover the unexpected effects of some substances.

The “noxious five” are already making life difficult for people in many parts of the world. High pollutant concentrations can be found in the megacities of Southeast Asia and Africa, for example. They include the Indian city of Mumbai, Pakistan’s Karachi, Lagos in Nigeria and the Chinese capital, Beijing. Some days, city dwellers don’t dare to go out onto the street without their face masks on.

Five nasty air pollutants are released into Earth’s atmosphere primarily via car exhausts and industrial emissions. A large proportion of the sulfur dioxide and particulate matter originates from power plants fired by fossil fuels; nitrogen dioxide, on the other hand, comes largely from the ever-increasing volumes of traffic worldwide. The effects of this “bad air” are considerable. Epidemiological studies have shown that, even when only small amounts are inhaled, the pollutants can cause cardiovascular diseases and lung cancer, not to mention asthma and chronic obstructive pulmonary disease (COPD).

One man who has been studying the noxious five for many years is Jos Lelieveld, Director at the Max Planck Institute for Chemistry in Mainz. However, the researcher isn’t directly involved with combating air pollution – he sees that as the job of governments. “Our work helps clarify the large-scale atmospheric processes associated with the bad air – especially in our globalized world,” says Lelieveld.

On the one hand, his team looks back in time into the history of the Earth’s atmosphere in order to determine how pollutant concentrations have developed over the past decades and centuries. The scientists are also interested in how the air quality will change in the future. Their main tool is EMAC (ECHAM-MESSy Atmospheric Chemistry) – the chemical atmospheric model they use to carry out computationally intensive global and regional simulations.

EMAC was developed during the past decade at the institute in Mainz. The ECHAM climate model of the Max Planck Institute for Meteorology in Hamburg, which had already been around for some time, was linked up...
with new, modular software for Earth system modeling (MESSy, Modular Earth Submodel System).

Today, EMAC is one of the very best models available to atmospheric researchers around the world, because it allows flexible computer simulation of the close spatial and temporal coupling of atmospheric chemistry and meteorological processes worldwide. The researchers can thus uncover, for example, what interactions exist between solar insolation, the water vapor content of the atmosphere, clouds, rainfall and atmospheric pollution. EMAC now provides them with a comprehensive Earth system model that can be used to investigate the chemical interactions between processes in the atmosphere, on land and in the oceans.

EMAC is the first to incorporate all five of the most noxious atmospheric pollutants into the calculations. While it sounds simple at first, it’s actually much more complicated than you would think. “In order to be able to simulate these pollutants, dozens of chemical components have to be incorporated into the model,” explains Leieveld. These include the precursor substances of ozone and aerosol particles. For example, a host of hydrocarbons are released into the atmosphere, where chemical interactions produce additional harmful substances.

Moreover, all of these members of the cast have different sources and sinks. Clouds, rain and exchange processes with vegetation play a particularly important role here. A key metric in EMAC is what’s known as the Multi-Pollutant Index, which combines the degree of atmospheric pollution caused by nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide and particulate matter in a single value.

**PRECISE FORECASTS OF ATMOSPHERIC POLLUTION**

The latest simulations at the institute in Mainz were based on actual emissions of the noxious five in 2005 and their trends in the ensuing years. They were used to calculate a business-as-usual scenario where it was assumed...
We need a better understanding of the effects the rapidly changing composition of the atmosphere has on global air quality and climate change.

that the current environmental laws and their implementation wouldn’t change significantly. The results were unique “global maps of atmospheric pollution,” which provide unusually precise forecasts for 2025 and 2050.

These worlds of the future show something of real concern: Air quality could worsen drastically over the coming decades in many parts of the world. Especially in the conurbations of the newly industrialized countries and developing nations, breathing would then ultimately become torture, and dense smog would be a part of daily life. It is thought that particularly China, Northern India and the Middle East could become real pollution hotspots by 2050. Then atmospheric pollution there could, in some cases, reach three times today’s levels.

According to the business-as-usual scenario, which assumes that no new air quality legislation will be introduced beyond what is currently implemented, the main protagonists of atmospheric pollution differ from region to region. In East Asia, it will probably be nitrogen oxides, sulfur dioxide and particulate matter that will really plague people. In Northern India and the Arabian Gulf region, the ozone levels could reach new record highs, as well.

CONCENTRATIONS OF POLLUTANTS ARE TOO HIGH

The cause of the increasing atmospheric pollution is the forecast economic growth in these regions. This will drastically increase the amount of traffic and industrial production – and thus emissions, too. In addition to the emissions from the petroleum industry, it is the high insolation by the Sun and other meteorological factors that are primarily responsible for the very specific pollutant profile in the Middle East, for example.

Europe and North America get off lightly compared to the potential regions of crisis. Here, the researchers expect only moderately rising levels. This is related to the greater environmental awareness on these continents, which already manifests itself in what are sometimes restrictive, though effective, environmental regulations. These include emission filters for coal-fired power plants, as well as efficient catalytic converters in motor vehicles. Nevertheless, the concentrations of atmospheric pollutants are still much too high even in Europe and North America, causing illness and premature mortality.

But the latest simulations are only the beginning. In the next step, the Max Planck researchers in Mainz want to take a closer look at many more factors that have an impact on atmospheric pollution. One thing they are planning is a study to investigate the effects of the South Asian monsoon on the redistribution of pollutants in the northern hemisphere and even in the stratosphere. “We need a better understanding of the effects of the rapidly changing composition of the atmosphere on global air quality and climate change,” says Jos Lelieveld.

He and his team also intend to train their sights more closely on the atmosphere over Africa in the future. A unique mixture of pollutants can already be found in the air there. Apart from large amounts of airborne desert dust, the mixture includes huge quantities caused by emissions from the burning of biomass.

Nowhere else on Earth are so many savannahs and forests being set on fire in order to create more space for agr-
culture. The Mainz-based researchers want to know how this bad air will evolve over the coming decades under the influence of global warming and the expected increase in industrial emissions.

As pessimistic as the vision of the future may be in large parts of the ailing atmosphere, there is still every reason for hope, because the cast of this environmental drama includes not only many villains, but also some heroes. The latter include the so-called hydroxyl radicals (OH radicals), as has been known for some time. They are a kind of fast-response force in the atmosphere, an effective “detergent” to cleanse the Earth’s atmosphere of pollutants.

THE POWER TO SELF-CLEAN IS ASTONISHINGLY RESILIENT

Each individual one of these “scrubbing molecules” consists of one hydrogen and one oxygen atom and has an average lifetime of less than one second. In the atmosphere, hydroxyl radicals form primarily from ozone and water molecules, usually in the presence of sunlight, or in the photolytic decomposition of hydrogen peroxide (H$_2$O$_2$).

As part of their chemical cleaning duties, the OH radicals oxidize pollutants such as carbon monoxide and other gases – methane, for example, which is particularly harmful to the climate. This process turns the original materials into water-soluble substances and
particles, which are packaged in water droplets by serving as condensation nuclei and are subsequently washed out of the atmosphere with the rain. Without the hydroxyl radicals, climate change would already have progressed much further and the air quality would be even worse than it is already. The one sticking point of this effective disposal process: hydroxyl radicals are also used up in the course of oxidation.

The researchers in Mainz discovered that their atmospheric concentration has nevertheless remained surprisingly stable over the years. This was confirmed by a 2011 study involving not only the Max Planck Institute for Chemistry, but also the National Oceanic and Atmospheric Administration (NOAA) in the USA.

The atmospheric scientists thus disproved earlier ideas that said that hydroxyl radical values would fluctuate annually by up to 25 percent. The results indicate that the self-cleaning power of the Earth’s atmosphere is less affected by the environmental changes to date than was thought.

“Although we predicted that the self-cleaning was well buffered, we were able to prove this only by taking systematic measurements over many years and employing state-of-the-art modeling methods,” explains Lelieveld. The results also make forecasting the climate and the global air quality more reliable, because computer models can now provide a better description of the composition of the atmosphere.

But why are the production and consumption of the atmospheric cleaning agents still almost in equilibrium despite increasing atmospheric pollution? The answer lies in recycling. This process is evidently widespread in Earth’s atmosphere. The Mainz-based researchers managed to get on the trail of the precise recycling sequence just over 18 months ago. Their starting point was a glaring discrepancy between the model calculations on the hydroxyl radicals at that time and the results of measurement programs in the field.

Above the Earth’s rainforest regions, in particular, the atmosphere had much more cleaning potential than really ought to be there, according to the simulations. How was that possible? The scientists proposed several hypotheses, only to discard most of them very quickly. Finally, their search for a solution to the problem led them to isoprene.

Like the much more familiar methane, this unsaturated hydrocarbon is produced in huge quantities by plants and released into the environment. At least 500 million tons of isoprene thus end up in the atmosphere around the globe every year. Most of it originates from the trees of the tropical rainforests, where it is used in the volatile oils of the scents, among other things.

Was there a connection between the high concentrations of hydroxyl radicals and isoprene? In order to test this, the atmospheric researchers used a virtual trick: they expanded one of the previous models of atmospheric chemistry by adding a further reaction cascade and assigned a Janus-faced effect to the isoprene. So when isoprene decomposes, the initial breakdown product is hydroperoxymaldehyde (HPAL). This uses up hydroxyl radicals.

**PLANT SCENT RECYCLES HYDROXYL RADICALS**

To help with the next step in the process, the scientists inserted a chemical switch: if a large number of “detergent” molecules are whizzing through the air at the time the HPAL is being formed, they help decompose the HPAL further. But if only a few hydroxyl radicals are present, the switch shifts: under the influence of sunlight, the hydroperoxymaldehyde then reacts with the atmospheric oxygen in a complex sequence of chemical reactions.

The end result is that more hydroxyl radicals are produced than are required to convert the plant- and tree-produced isoprene to HPAL. That was the theory. But there was still no practical test for the improved model. New simulations then brought further proof: their thinking was correct; actual measurements and model calculations were again in agreement.

This recycling of the cleaning agents is an important element in keeping the air clean, especially in the tropics. "But our results also mean that rising isoprene emissions, as we expect from global warming, don’t actually make...
the climate effect worse,” concludes Lelieveld. This is because a higher concentration of isoprene in the air can support the production of hydroxyl radicals – and help combat climate-damaging gases.

The mechanism uncovered in 2012 may, however, not be a special case. The researchers in Mainz now suspect that several natural and manmade pollutants emitted into the air also have an antagonistic effect and could buffer the self-cleaning power of the atmosphere in a manner similar to isoprene.

That there could be some truth in this is shown indirectly by another example from the Earth system with its diverse interactions between the atmosphere, lithosphere, hydrosphere and biosphere. Nitrogen over-fertilization has long been considered a massive problem because it can result in dangerous nitrates getting into the groundwater. Acidic soils also have a bad image; they are one of the reasons why forests are dying. But apparently two villains together can do some good.

**DOES CLIMATE CHANGE CREATE MORE HYDROXYL?**

This fact was uncovered by a new nitrogen cycle path that was discovered in lab experiments a short while ago. According to the discovery, nitrous acid (HNO$_2$) is formed out of nitrite ions and water in soils that are well supplied with nitrogen. The higher the nitrite concentration and the more acidic the soil, the more HNO$_2$ is produced. This then gets into the atmosphere as gaseous nitrous acid (HONO), where it serves as the starting product for the formation of hydroxyl radicals.

As climate change advances, the driving force behind the production of this detergent could become more and more important. In a predicted triad of increased fertilizer use, rising soil acidification and global warming, scientists think significantly more nitrous acid will likely be released from the soil, especially in developing countries. The end effect is that more fodder is available for the formation of hydroxyl radicals and the self-cleaning power of the atmosphere increases, at least locally.

The stock of cleaning agents in the atmosphere has thus produced some good news. But can pollutants that happen to have an antagonistic effect and effective buffering mechanisms really solve the problem of the predicted dramatic rise in pollutant concentrations? No, says Jos Lelieveld decisively: “Even if these phenomena mean we have less cause to worry about our atmosphere, we should still do all we can to reduce the emission of climate-active gases and toxic air pollutants as much as possible.”

The Mainz-based researchers believe that new legislation and technologies to reduce industrial, traffic and household emissions are an essential element in the battle against atmospheric pollution. We need to ensure that the business-as-usual scenario doesn’t become reality. Particularly for the regions considered to be future pollutant hotspots, this could possibly be their only salvation. But can such measures even be implemented at all in countries with enormous economic growth?

The air is a health risk: The maps of the eastern USA, Europe, and South and East Asia show how high the mortality rate there was in 2005 due to cardiovascular diseases, lung cancer and respiratory diseases that can be traced back to particulate matter and ozone pollution (given in deaths per 10,000 square kilometers).
Lelieveld is optimistic: “I see no reason why better environmental laws and technologies shouldn’t be possible in China, India and other countries.” He is utterly convinced that they don’t harm economic growth – especially long term. But he also says: “Environmental regulations are like many highly effective operations: it’s a case of no pain, no gain.”

**BETTER AIR QUALITY BRINGS HEALTH COSTS DOWN**

First, there has to be substantial investment in the development of green technologies, such as energy-efficient cars and low-emission power plants, but ultimately, the optimized technologies also benefit industry and the national economy in question. Better air quality, for example, brings down costs for the health system, and workers take less time off due to illness.

What is possible in terms of clean air in a very short time was demonstrated by China in 2008 when it hosted the Olympic Games. Back then, it applied numerous environmental regulations and succeeded in reducing the dramatic atmospheric pollution to such a degree that the athletes had at least reasonably acceptable conditions in which to compete. Yet the other side of the coin is that China has since returned to its old ways. Air pollution has long been back at the same levels as before the Olympics.

Not only newly industrialized and developing countries have a duty to fight for better air. Europe and North America have no reason to be complacent, either. “Atmospheric pollution moves around the world as fast as money does,” is the interesting comparison Jos Lelieveld draws. The emissions billowing out of power plant smokestacks and car exhaust fumes in East Asia can reach us within one or two weeks on global winds such as the jet streams.

The existing environmental regulations and technologies must therefore be advanced here at home, as well, and adapted to possible future conditions. “Our research serves as the basis for applied projects, which, in turn, will lead to low-cost measures for keeping the air clean and help optimize the networks that monitor atmospheric pollution,” explains the Max Planck Director.

Recent calculations undertaken by the Mainz-based scientists show how vital the fight is against the noxious five and other atmospheric pollutants. At present, some three million people around the globe die every year because of the anthropogenic bad air – 50,000 of them in Germany alone. If no measures are taken against the pollution of the Earth’s atmosphere in the next few decades, the “deadly quintet” will be responsible for many more illnesses and deaths in the future.

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**TO THE POINT**

- Five atmospheric pollutants (nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide and particulate matter) from car exhausts, industrial emissions and the burning of biomass harm both humans and the environment. Moreover, a host of natural and man-made hydrocarbons chemically interact with these pollutants in the atmosphere, forming additional noxious gases and particulates.

- Researchers use the EMAC model to simulate the close spatial and temporal coupling of atmospheric chemistry and meteorological processes on the computer. The outcomes are used to assess the effects on human health worldwide.

- A drastic worsening of the air quality could take place during the coming decades, especially in the conurbations of the emerging industrialized countries, causing premature mortality.

- Although the quantities of cleaning agents in the atmosphere have remained astonishingly constant over the years, new legislation and technologies are needed in order to counteract further increases in atmospheric pollution.
The amounts of carbon dioxide and other trace gases that vegetation and soil exchange with the atmosphere affect the climate in a variety of ways. Markus Reichstein and his colleagues at the Max Planck Institute for Biogeochemistry in Jena are analyzing this complex structure – with the aid of a global network of measuring stations and new data analysis methods.

A new generation is about to take over in climate research: When the first part of the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is published in fall 2013, the results will be based on computer simulations of Earth’s climate, in which the life on Earth plays a much greater role than in the past. These latest models now include far more of the processes that take place in the biosphere on land and in the oceans than those of a few years ago. And they include the cycle of the element carbon, which heats the atmosphere when it is in the form of carbon dioxide or methane, but is the key building block of the biosphere when it is in the form of organic compounds. The climate researchers now call their computer programs Earth system models, in contrast to the earlier ocean-atmosphere general circulation models, which represented state of the art research in the fourth IPCC report in 2007.

Attempting to calculate the processes of life with computers is, of course, no easy undertaking. When attempting to illustrate the complex processes on Earth to his audience, Markus Reichstein likes to compare the planet to an organism. “This image is more fitting than that of a purely physical machine,” says the Director of the Department of Biogeochemical Integration at the Max Planck Institute for Biogeochemistry in Jena. Like an organism, Earth has a metabolism in which such elements as carbon, nitrogen, phosphorus and water play an important role. The Earth system comprises various components that are coupled with one another, and this system is constantly evolving.

“But the individual parts of the Earth system – the atmosphere, oceans, areas of ice and snow, and terrestrial ecosystems – aren’t as closely interrelated as the organs of an organism,” he says. The lung is a vital organ for us humans, for example. What would happen if the rainforests, which are often...
(inappropriately) called the lungs of the planet, were to disappear? “That would certainly be a critical event, but it is highly unlikely that life would completely disappear from Earth,” says Reichstein.

The problem is that even the new Earth system models aren’t yet particularly good at predicting how the biosphere reacts to changes in the climate – and conversely, how changes to the vegetation and soils affect the global climate. “At present, the terrestrial biosphere absorbs around a quarter of the anthropogenic carbon emissions, but it’s uncertain whether this natural sink will remain as strong in the future as it is now,” says Reichstein. His department focuses on how the atmosphere and biosphere affect each other.

In recent years, he and his colleagues discovered some unexpected facts about the biosphere as a climatic factor. In 2010, for example, they reported that the savanna vegetation is the second largest important photosynthetic carbon absorber on Earth, following closely on the heels of the rainforests. Previously, no one had expected that a quarter of the organic material that plants produce globally is created here.

In a different study, the researchers in Jena showed that the plant growth in many regions of the world depends mainly on how much water is available to the plants in the form of soil moisture – and less on temperature. “At first glance, this sounds relatively trivial, but it isn’t described adequately in the current Earth system models,” says Reichstein. It isn’t yet possible to accurately predict how the precipitation will be distributed, nor how terrestrial ecosystems will react to it.

Sönke Zaehle, head of the Terrestrial Biosphere Modelling research group in Reichstein’s department, and his team made another surprising discovery. In 2011, he and his colleagues investigated the climatic effect of anthropogenic reactive nitrogen. On the one hand, this man-made ‘fertilizer’ counteracts global warming: plants grow better when they have a good supply of nutrients, and they therefore absorb more carbon dioxide (CO₂) from the atmosphere. But fertilizer also has a damaging impact on the climate, because fertilized soil releases more nitrogen oxides, including the potent greenhouse gas nitrous oxide. The researchers’ model calculations showed that the nitrous oxide emissions nearly cancel out the positive effect of the plant growth.

It is presumed that there are still many other, as yet unknown, relationships or feedback effects in the biosphere that impact the climate. “Whenever biology is involved, the system...”
becomes significantly more difficult to predict,” says Miguel Mahecha, head of the Global Empirical Inference research group. While it’s possible to provide a good description of the processes in the atmosphere with physical equations, we currently know little about the mathematical rules that govern the biosphere.

The soil represents a further large element of uncertainty. To date, researchers aren’t sure how much carbon is stored in the global soils, or how long it remains there (cf. MaxPlanckResearch 1/10). For example, they now think that the amount of carbon in Earth’s top layer is twice as much as they estimated 20 years ago. “We also call the soil the ‘dark matter’ of Earth system research,” jokes Markus Reichstein.

He and his colleagues are therefore pursuing a new line of inquiry to discover the rules of the biosphere. “The motto here is: Data first,” says Miguel Mahecha. The Jena-based researchers use satellites and measuring stations to monitor the condition of the ecosystems as accurately as possible. They then use innovative methods from the field of machine learning to analyze the data and search for patterns and unknown relationships.

The Fluxnet measurements also provide the researchers with information about how much of various nitrogen oxides, and how much water vapor or methane the plants release in forests (left) or bog land (right).
the vertical direction, on the one hand, and the concentration of various trace gases on the other, both ten times per second. Since the air becomes turbulent just above the vegetation, the measuring equipment sometimes records a gust of air going up, and sometimes one going down. If the airflows toward the atmosphere contain a higher CO₂ concentration over a certain period of time than those going down, the result is an overall flow of CO₂ from the biosphere to the atmosphere.

**SEARCHING FOR UNKNOWN PATTERNS**

“Until a few years ago, there were some technological limits to this method, but now it’s gaining great momentum,” reports Markus Reichstein. He was one of the researchers who were instrumental in the existing regional networks in Europe, North America, Asia and Australia joining forces to form the global Fluxnet network. The data is stored centrally and processed uniformly, and is freely accessible to all participating researchers.

In conjunction with the satellite measurements, the Fluxnet data provides a relatively good overview of the condition of the various ecosystems on Earth. “The only places where the network is still spread too thinly is in the tropics and the very high latitudes,” says Reichstein. Of course it isn’t possible to observe everything at every point in time at every point on Earth, but the researchers in Jena are working on using the Fluxnet locations and the satellite data to calibrate their statistical models in such a way that they can describe any spot on Earth, including those between the measurement points. “This provides us with a kind of diagnosis: we are describing Earth’s present condition,” explains Reichstein.

He and his colleagues trawl through this data for unknown patterns and relationships, collaborating closely with researchers in Bernhard Schölkopf’s group at the Max Planck Institute for Intelligent Systems in Tübingen. The mathematicians are experts on machine learning and develop, for example, algorithms for facial recognition. The researchers in Markus Reichstein’s department use these same algorithms to search for patterns in their climate and vegetation data; one doctoral student works with both groups. “The collaboration works very well, and we have already published a joint article and are working on further studies,” says Miguel Mahecha.

The collaboration also enables the developers in Tübingen, particularly those in Stefan Harmeling’s research group on Computational Imaging, to make progress with their work, because ecological data poses new challenges. For instance, ecological measurement data is always fraught with very high uncertainties, it is sometimes recorded in different units, and there are systematic gaps in the data, as well as cyclic events such as the seasons, periodic climate changes with long-term cycles, and trends such as climate change.

Moreover, the volumes of data in Earth system research can quickly take on huge dimensions. In the Jena-based group’s simplest datasets, there is one data point every 0.5 degrees, yielding more than 75,000 points for each time interval for the entire land surface of Earth. The necessary calculations are already a challenge for the developers. In the future, the spatial resolution will be significantly higher, and they can expect to have hundreds of millions of data points.

**A DIAGNOSIS OF EARTH’S PRESENT CONDITION**

But it’s worth the effort: “This is enabling us to find relationships that can’t be explained with the current Earth system models,” says Markus Reichstein. The study on the dependence of plant growth on soil moisture, for example, which was published in the journal *Science* in 2010, was based on the new method. The researchers were thus also able to create a statistical model that can be used to predict, among other things, how much organic matter the various ecosystems produce around the globe under specific climate conditions.

When Reichstein and his colleagues find a previously unknown relationship in their data, they search for a physical or biological explanation. The process can then, in turn, be described in equations and be incorporated into the MPI-ESM Earth system model of the three Max Planck Institutes for Meteorology in Hamburg, for Biogeochemistry in Jena, and for Chemistry in Mainz. Together with some 20 additional Earth system models from other institutions, the Max Planck model has computed...
the scenarios that will be published in the fifth IPCC report.

While Markus Reichstein’s department concentrates on deriving the carbon footprint of the terrestrial ecosystems from the point measurements from the Fluxnet stations – that is, working from the bottom up, so to speak – the researchers in the Biogeochemical Systems Department of the Max Planck Institute in Jena pursue the opposite approach: they work from the top down, as Director Martin Heimann says.

“We measure the CO$_2$ concentration in the atmosphere at different heights, for example with the Zotino Tall Tower Observatory, a 300-meter high measurement tower in West Siberia,” explains the physicist. These measurements provide an average of the CO$_2$ concentration, similar to the one that can be seen in the famous Mauna Loa curve. The values are representative for a larger region: they show how the plants within a radius of many hundreds of kilometers take up carbon dioxide and release it again over the course of a year.

Both methods provide a picture of the carbon footprint of the vegetation, but from different points of view – like in a library, where it’s possible to monitor the overall holdings, or to record the incoming and outgoing books. In Sönke Zaehle’s research group, which belongs to both Markus Reichstein’s and Martin Heimann’s department, researchers are currently working on the challenge of linking up the two methods in a joint model.

The aim is to reduce the uncertainties in the data. “Ultimately, we expect it to result in better datasets,” says Heimann. The uncertainties owe to the fact that Earth’s material budget is much more difficult to monitor than the holdings of a library. This is why there are discrepancies between the measurements taken directly above the vegetation and the observations made in higher layers of the atmosphere.
The researchers will soon have formed a consistent picture from the results of both measurement methods. They then plan to apply the model produced by combining the two methods to current research issues for the first time, says Heimann. This will give them a much clearer idea of how much carbon the terrestrial biosphere absorbs and releases, and when and where it does so.

**ALGORITHMS HUNT FOR EXTREME EVENTS**

An important new research field for the institute in Jena involves extreme climate events, such as droughts, storms or weeks of persistent rain. In CARBO-Extreme, the EU project coordinated by Markus Reichstein, an international team of researchers is investigating what effects such extreme events have on the carbon balance of the terrestrial vegetation. Many researchers suspect that extreme events cause more turmoil in the carbon cycle than was previously assumed. But how strongly they change the balance is still unclear – one reason being that not all extreme events are detected in the first place.

“We identify such events with, among other things, the algorithms of our partners in Tübingen,” says Miguel Mahecha. Using only satellite data that describes how green the plant cover is, Mahecha and his colleagues searched, for example, for periods of extremely low vegetation activity that have occurred during the last 30 years. The researchers then correlated the anomalies in the vegetation with the climate.

As expected, the algorithms found known droughts, such as the summer heat waves in Europe in 2003 and in Russia in 2010. A dry spell in the Amazon in 2005, however, remained hidden, probably because the many clouds often render the rainforest invisible to satellites. The program also detected previously unknown droughts, primarily in remote regions of the world.
When they compared the model with the climate data, the researchers found that most vegetation anomalies were triggered by water stress. But not always: for about 9 percent of the events, the climate data provided no apparent reason as to why the vegetation suffered. “Perhaps it is a lag effect,” suspects Miguel Mahecha. Although some trees succeed in surviving a drought, they are then so stressed that they fall victim to even insignificant climate fluctuations or insect infestations in the following year.

Overall, says Mahecha, extreme events are more likely to have a negative effect on the carbon balance: “A strong meteorological anomaly often causes the ecosystems to lose CO2.” In the summer heat wave of 2003, for example, the drought resulted in as much carbon dioxide being lost in Europe as the plants store in five normal years. It also turned out that it is primarily the most extreme events that are important for the CO2 balance. “These findings will now be integrated into the models of the Earth system,” says Markus Reichstein.

He and his colleagues test the quality of the various Earth system models by comparing the calculations of the programs with their data on the actual condition of the biosphere. In this way, they investigated, for example, how well the models describe the impact of temperature on soil respiration. In other words, they want to know whether roots and soil microbes breathe out more carbon dioxide when it becomes warmer. The Earth system models use different hypotheses for this purpose. “We analyze whether the patterns we see are described correctly by the models,” explains Reichstein.

The studies from Jena show that, like the growth of vegetation, the CO2 evolution from the soil really depends primarily on the precipitation and the water balance. However, the most important driving force in the current Earth system models is temperature. “Our work shows that the water cycle often plays a more important role for the biogeochemistry than temperature. More attention must be paid to this in the future,” says Reichstein.

The processes of life will probably play a much greater role in the climate models of the future than has so far been the case. The invasion of foreign species or the question as to the effect roots have on the soil aren’t yet something that Earth system models address, for example. So the geo-ecologists from Jena still have a lot to do before they have completely understood the organism we call Earth.

TO THE POINT

- The ocean-atmosphere models on which the forecasts of the Intergovernmental Panel on Climate Change (IPCC) are currently based are being replaced by Earth system models. Here, processes in the land biosphere, such as the carbon cycle, play a much more important role in predicting the future evolution of the climate.
- The material cycles between the biogeoosphere and the atmosphere impact the climate and vice versa in a complex way. The distribution of the precipitation is at least as important as the temperature.
- Geoscientists and climate researchers must acquire a better understanding of how the carbon cycle depends on the water cycle, and incorporate this in their models. Extreme climate events such as droughts and floods have a great impact on the CO2 balance: over just one summer, a drought can release as much CO2 as was stored in vegetation and soil over the course of five years.

GLOSSARY

Earth system: The complex system that is our Earth can be understood as a whole only if the diverse interactions between atmosphere, hydrosphere (mainly oceans, but also lakes and rivers), geosphere and lithosphere (solid terrestrial surface), biosphere (ecosystems), cryosphere (regions covered in ice and snow) and, as long as humans have existed, also the anthroposphere are taken into account.

Machine learning: Computer programs that identify patterns from sets of data and create appropriate models that can be applied to new, but similar data.
Country Bumpkins Have More Enthusiasm for New Things

Urban life changes the personality of blackbirds and makes them skeptical

City folk are generally assumed to be more open to new trends than those living in rural areas. Urban life also seems to change the character of animals that have successfully colonized our cities – but the other way around. Researchers at the Max Planck Institute for Ornithology in Radolfzell have discovered that urban-born blackbirds are less curious about new objects than their country cousins. They are also more likely to be put off by unfamiliar stimuli. When it comes to settling in cities, evolution seems to have favored certain personality types.

Blackbirds clearly have to deal with constantly new, potentially dangerous situations in the fast-paced world of the city and have thus developed a general skepticism about anything new. The more settled way of life in the country, on the other hand, provides for more reliable living conditions. Scientists around the world have also noticed personality differences between city and country dwellers in other animal species – it’s a global phenomenon. (Global Change Biology, June 19, 2013)

Chaos with Unfamiliar Swirling

A new form of turbulence explains why oil containing a low concentration of a dissolved polymer flows with almost no friction through pipelines

A team of researchers at the Max Planck Institute for Dynamics and Self-Organization in Göttingen and Saarland University in Germany have discovered a new type of turbulence. The chaotic state, which the scientists call elasto-inertial turbulence, occurs in polymer solutions, such as oil that is pumped through pipelines. Small quantities of a polymer have long been added to the fossil fuel to reduce the friction of the oil by 80 percent when it is transported. This significantly reduces the energy required for the pumps. Researchers working with Björn Hof at the Max Planck Institute in Göttingen can now explain why this is. Oil to which a small amount of polymer has been added – when compared with oil flowing without the polymer – becomes turbulent only at higher flow speeds. The elasto-inertial turbulence that occurs here at high flow speeds also generates less friction than the normal turbulence that transforms water flows or pure oil flows into wildly swirling streams. (PNAS, online, June 11, 2013)

Chaos with new properties: Swirls always pervade the entire flow in the presence of elasto-inertial turbulence (left), unlike in normal chaotic flows (right). They are also perpendicular to the direction of the flow, which runs vertically in this picture. With normal turbulence, the turbulent swirls extend in the direction of the flow. The swirling regions in the flow are shown in orange; the blue sections indicate areas that are stretched.
...and now for the weather on Mars

Snow regularly falls in the north of the red planet and can be forecast quite accurately

The seasonal ice that is a feature of winter on Mars has two origins: some of the carbon dioxide from the atmosphere condenses directly on the surface — similar to the way a layer of frost forms on Earth during cold, clear weather; some of it freezes into tiny ice crystals in the atmosphere, which form clouds and fall as snow. For the first time ever, scientists at Tohoku University in the Japanese city of Sendai and the Max Planck Institute for Solar System Research in Katlenburg-Lindau, Germany, have established a link between the appearance of such ice clouds and a wave-like weather phenomenon characterized by periodic fluctuations in pressure, temperature, wind direction and wind speed.

These waves can be found with astonishing reliability in the Martian northern hemisphere between fall and spring. They propagate eastward with a uniform period of five to six days. Additional waves with higher frequencies can be observed close to the surface. According to the scientists’ calculations, snowfalls in certain northern regions can be forecast well in advance. These types of weather forecasts would enable Mars rovers to avoid heavy snow showers on their routes. (Geophysical Research Letters, April 29, 2013)

Revealing Games behind Bars

An experimental study that researchers at the Max Planck Institute for Research on Collective Goods acted out with prisoners produced an interesting result: convicted criminals are in no way more selfish than average citizens who have never been in conflict with the law. Moreover, people evidently don’t become criminals because they are more self-seeking than others. At the juvenile correctional facility in Adelsheim, Germany, 58 inmates agreed to take part in a “dictator game.” This involved sharing or not sharing, and the behavioral economists had a tried-and-tested tool to determine the social preferences of the participants. The result was that only 34.48 percent of participants proved to be selfish and kept the entire five euro endowment entirely for themselves; when the game was played with “normal citizens,” the figure was 36.11 percent.

The researchers repeated the game three years later with a new group of inmates. The same results were obtained. The second time around, the recipient of the donations was changed: this time, the small donation would go to the German charity Brot für die Welt. The prisoners gave more than before to their fellow prisoners. Moreover, as in the previous game, they were also more generous than the average citizen. (Preprints of the Max Planck Institute for Research on Collective Goods 2013/5)

Charcoal in the Ocean

Wildfire residue is washed out of the soil and transported to the sea by rivers

An important factor in the Earth’s carbon cycle used to be completely overlooked. An international team of researchers working with Thorsten Dittmar at the Max Planck Institute for Marine Microbiology in Bremen has calculated that approximately 25 million tons of charcoal is carried by rivers from the land into the sea each year. Wildfires burn millions of hectares of vegetation each year, resulting in large quantities of charcoal on land. Geoscientists previously thought that the charcoal remained in the ground. As the group working with the Bremen-based Max Planck researchers has now shown, however, charcoal accounts for 10 percent of the world’s total amount of dissolved organic carbon compounds in rivers, lakes and oceans. These new findings help us gain a better understanding of the global carbon cycle through which the greenhouse gas carbon dioxide is released into the atmosphere. (Science, April 19, 2013)
It was one of the worst famines in history: In 1845 and subsequent years, a fungal disease destroyed vast swaths of Europe’s potato harvests. In Ireland alone, one million people starved to death; at least another million emigrated. An international team including researchers at the Max Planck Institute for Developmental Biology in Tübingen, Germany, reconstructed the evolution of the pathogen *Phytophthora infestans*. To do this, the scientists used historical herbarium samples for the first time.

Their analysis of the fungal genetic material showed that the 19th-century famine was caused by the HERB-1 pathogen strain, which is closely related to a North American strain. It is thus highly likely that the potato blight came to Europe through North America and raged throughout the world for more than 50 years. The pathogen was probably spread from its center of origin in the Toluca Valley in Mexico by the Spanish conquistadors in the early 16th century. The first resistant potato varieties were bred at the beginning of the 20th century, which means that the HERB-1 strain is now likely to be extinct.

*eLife*, May 28, 2013

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New Keyboard for Touchscreens

With an optimized keyboard layout, it is significantly faster to type with two thumbs than on a keyboard with a conventional layout.

Fast typists don’t use ten fingers to type on a smartphone or tablet, but rather two thumbs. In the future, they could be able to move their fingers even more deftly. A team working with Antti Oulasvirta at the Max Planck Institute for Informatics in Saarbrücken, Germany, has designed a keyboard layout for touchscreen devices. The researchers created a model of thumb movements and, using a computer algorithm, searched among several million potential keyboard layouts for one that would allow users to enter text as quickly as possible using alternating thumbs.

The team initially optimized the layout of the keyboard for the English language. This involved placing all vowel sounds, with the exception of the letter Y, in the area for the right thumb, while the left thumb was assigned more keys. The new design, dubbed “KALQ,” allowed users to type 34 percent faster than on devices with the conventional QWERTY layout. The keyboard layout can also be optimized for other languages in the same way.


In the KALQ layout, which is optimized for inputting English text on touchscreens, all the vowel sounds except Y are located in the area near the right thumb; the area nearest the left thumb has more keys.
Mysterious Flashes in the Sky

Cosmic radio bursts point to cataclysmic events in the distant universe

An international team of researchers including scientists from the Max Planck Institute for Radio Astronomy in Bonn, Germany, has detected bursts of radio waves that appear to have originated billions of light years away at a time when the universe was between six and nine billion years old. The researchers are baffled about the origins of these emissions. Four Fast Radio Bursts (FRBs) with durations of only a few milliseconds were detected at high galactic latitudes in the southern sky.

The extremely short duration of the bursts and the inferred great distance imply that they were caused by some extremely high-energy cosmological event, such as two neutron stars merging, a sun dying or a star being swallowed by a black hole.

The researchers now want to use their findings to study the properties of the intergalactic space where the bursts occurred. (Science, July 5, 2013)

Resilient Harlequin

Biological weapons give Asian ladybugs the upper hand over their European relatives

Once introduced for biological pest control, Asian ladybug Harmonia axyridis populations have been increasing uncontrollably in the US and Europe since the turn of the millennium. The species has also been proliferating rapidly in Germany; conservationists fear that the Asian ladybug, also known as the harlequin ladybird, will out-compete native beetle species. Scientists at the University of Gießen and the Max Planck Institute for Chemical Ecology in Jena, Germany, have now discovered why this animal is so successful.

The invader’s body fluid contains what are known as microsporidia – single-celled, fungus-like parasites. The Asian ladybug is obviously resistant to these parasites in its own body. However, transferred to Germany’s native species, microsporidia can be lethal. The invader is also better able to fend off infections. Its body fluid contains greater quantities of an antibacterial compound known as harmonine, and more antibiotic peptides than the seven-spot ladybird (Coccinella septempunctata), which is native to Germany. (Science, May 17, 2013; Biology Letters, March 6, 2013; Proceedings of the Royal Society of London B, November 21, 2012)

Crucial difference: Colonies of E.coli (white dots) die off in the area surrounding the Asian ladybug (Harmonia axyridis, left) (circle). The native ladybug species Coccinella septempunctata (middle) and Adalia bipuncata (right), on the other hand, do little or nothing to stop the bacteria.
Astronomers at the Max Planck Institute for Radio Astronomy and the Max Planck Institute for Extraterrestrial Physics in Germany have studied the most detailed observation ever of the area surrounding a supermassive black hole at the center of the active galaxy NGC 3783. To do this, they used the European Southern Observatory’s Very Large Telescope Interferometer. The black hole has a mass approximately eight to ten million times that of the Sun, and is surrounded by a hot disk of gas. Matter falls into the gravity trap from the inner edge of this disk, heating the disk and making it very bright. It is surrounded by a donut-shaped torus of gas and dust. This dust is heated by the radiation from the gas disk and emits the heat energy as infrared light.

In addition to this radiation, which scientists have known about for a long time, the astronomers also discovered cooler dust above and below the radiation. This dust has a temperature of around 300 degrees Kelvin, in other words, room temperature. The streams of dust extend perpendicularly to the hot dust torus toward the polar regions. Depending on the wavelength, between 60 and 90 percent of the radiation in the mid-infrared originates from the two pillars of dust and not – as was previously assumed – from the torus. This raises a number of questions, such as the origin of the polar streams. (The Astrophysical Journal, online, June 20, 2013)

Massive, turbulent monster: The artist’s impression shows the surroundings of the supermassive black hole at the heart of the active galaxy NGC 3783. New observations not only point to a torus of hot dust around the black hole, but also to a wind of cool material in the polar regions.

Mobility in the City

A model that describes movement over short distances and short periods could help manage traffic flows better

Transportation planners could soon have an easier time of it. An international team including Vitaly Belik from the Max Planck Institute for Dynamics and Self-Organization in Göttingen, Germany, developed a model based on data collected in Paris and Chicago that describes the mobility of people over short distances – such as in a city – and short periods of time. The researchers found that, on weekdays, 90 percent of people visit a maximum of six different locations, including their own home. They use just 17 of more than one million possible trip sequences to get to their intended destinations on a given day.

Models describing mobility across large distances and over long periods of time already exist. The new findings could help urban planners plan inner-city traffic routes and manage traffic more effectively. They could also be useful in helping prevent epidemics in smaller areas. (Journal of the Royal Society Interface, May 8, 2013)

Everyday routes: People can visit several places using very different routes, but in practice, they actually use very few of them. The diagram shows the number of relevant mobility profiles that can be used to reach between three and six different destinations. The number of destinations is compared to the number of potential routes. The central location, usually the person’s home, is shown in red.
Preference in Mating

Mate choice is a key factor in the evolution of new animal species. Researchers at the Max Planck Institute for Evolutionary Biology in Plön, Germany, investigated whether house mice would mate with each other even if they were from two populations that had been separated from each other for a long time. To do this, they brought together wild house mice from southern France and western Germany in a research enclosure several square meters in size. The enclosure was divided up with wooden walls and contained nests made of plastic cylinders and plastic tubes. Both populations had been geographically separated for about 3,000 years.

While the mice initially mated with each other quite randomly, the German-French hybrid offspring were significantly more choosy: they showed a preference for breeding with partners who came from their father’s original population. The paternal influence in choosing a mate therefore fosters the creation of genetically uniform groups, thus accelerating the speciation process.

(Molecular Ecology, online, March 18, 2013)

A Good Wire for Nanoelectronics

Silicon nanowires become doped with unexpectedly large amounts of aluminum during growth, increasing their conductivity

Nanoelectronics has taken another step forward. An international team including researchers at the Max Planck Institute of Microstructure Physics in Halle, Germany, discovered an effect that can be used to produce particularly conductive silicon nanowires, such as those used in electronics. Aluminum is used as the catalyst to grow such nanowires. Tiny drops of aluminum on a silicon substrate trap silicon from the gaseous compound silane. As soon as the aluminum droplets are saturated with silicon, they still continue to absorb the semiconductor’s atoms, but they begin to deposit crystals underneath, with the result that silicon wires gradually begin to form there. As the researchers working with Oussama Moutanabbir then discovered, significantly more aluminum atoms than expected go into the wires. The high proportion of aluminum – referred to in semiconductor technology as doping – improves the conductivity of the wires. (Nature, April 4, 2013)

Chlamydia Wreaks Havoc in Genetic Material

The sexually transmitted bacteria evidently pave the way for the development of cancer

Cancer isn’t just a question of genetic makeup or damaging environmental influences – it can even be contagious. In addition to various viruses, the gastric bacterium Helicobacter pylori can cause cancer. Scientists now suspect, however, that Helicobacter is just the tip of the iceberg. Particularly Chlamydia trachomatis, one of the most frequently sexually transmitted bacteria, is suspected of being a factor in the development of ovarian cancer.

Researchers at the Max Planck Institute for Infection Biology in Berlin, Germany, have now found another clue to indicate that Chlamydia can actually cause cancer. When these pathogens multiply, they cause immense damage to the genetic material of their host cells, which can’t be fully fixed by the cell’s repair mechanisms. This quickly leads to multiple mutations in the genetic material. The bacteria also prevent the mutated cells from dying off. They prompt them to continue growing – the first step to becoming a cancer cell. (Cell Host & Microbe, June 12, 2013)
Physics Has a Core Problem

Physicists can solve many puzzles by taking more accurate and careful measurements. Randolf Pohl and his colleagues at the Max Planck Institute of Quantum Optics in Garching, however, actually created a new problem with their precise measurements of the proton radius, because the value they measured differs significantly from the value previously considered to be valid. The difference could point to gaps in physicists’ picture of matter.
The atmosphere at the scientific conferences that Ran-dolf Pohl has attended in the past three years has been very lively. And the physicist from the Max Planck Institute of Quantum Optics is a good part of the reason for this liveliness: the community of experts that gathers there is working together to solve a puzzle that Pohl and his team created with its measure-ments of the proton radius. Time and time again, speakers present possible solutions and substantiate them with mathematically formulated arguments. In the process, they sometimes also cast doubt on theories that for decades have been considered verified. Other speakers try to find weak spots in their fellow scientists’ explanations, and present their own calculations to refute others’ hypotheses. In the end, everyone goes back to their desks and their labs to come up with subtle new deliberations to fuel the debate at the next meeting.

In 2010, the Garching-based physicists, in collaboration with an interna-tional team, published a new value for the charge radius of the proton – that is, the nucleus at the core of a hydrogen atom. The charge radius describes the space in which the positive charge of the nucleus is concentrated. To determine this number, the researchers working with Randolf Pohl used a different method than the one used pre-
viously, and obtained a result that differs significantly from the figure that used to be considered valid. So significantly, in fact, that the difference can’t be explained by the measurement accuracies of the two methods. And to keep the tension from subsiding, Randolf Pohl and his colleagues recently refined their measurement result further, thus making it clear: more precise analyses don’t make the problem go away.

For years, Randolf Pohl and his colleagues thought that their measuring instrument wasn’t sufficiently accurate: they first conducted an experiment in 2003 to determine the size of a proton. However, they didn’t discover the signal that would give them information about it. “But this wasn’t due to the inaccuracy of our method, but rather to the fact that we hadn’t expected such a large deviation,” says Randolf Pohl. The researchers had selected too small a window for their measurements.

According to the latest measurements by Pohl’s team, the charge radius of the proton is 0.84087 femtometers (one femtometer is a millionth of a millionth of a millimeter) and the measuring uncertainty here is just ± 0.00039 femtometers. With the previously common measuring method, two independent groups recently determined that the charge radius must be 0.879 ± 0.009 femtometers and 0.875 ± 0.011 femtometers, respectively.

In other words, the difference between the measurements is 0.036 femtometers, or 4 percent. That doesn’t sound like much, but in the context of the given uncertainty of the measuring accuracy, it is actually a lot. The discrepancy corresponds to seven combined error bars and is thus significantly larger than one would expect if different experiments merely yielded slightly different results in the context of statistical fluctuations.

NO SYSTEMATIC ERROR WAS FOUND

Just how great the difference is between the results and uncertainties of the two different methods of measuring the proton radius can be illustrated by transferring them to a map of Germany. Suppose one were to put the result obtained by Randolf Pohl’s team in the center of Munich, and the competing measurement in the center of Hamburg. Then the uncertainty of the Munich value would correspond to the distance between the two Munich neighborhoods Pasing and Trudering. The Hamburg measurement, in contrast, would be so imprecise that the actual value might very probably even lie somewhere between Flensburg and Hanover. Clearly, this is going to cause problems – it would be no different than if one were to suddenly look for Hamburg’s St. Michael’s church on Munich’s main square, Marienplatz.

To explain the great difference between the two measurements, physicists initially scoured the two methods for systematic errors that might skew the result. “It could, of course, be the case that we overlooked such an error, but we searched very carefully and found nothing,” says Randolf Pohl, whose team took a new approach to measuring the proton radius some 15 years ago, and published the first result of this work in 2010.

The researchers used laser spectroscopy to determine how high the energy of a photon has to be to transport an exotic hydrogen atom from one special energy state to another. The energy of some of these states depends on the proton radius, and that of others doesn’t. If the atom is taken from one state that appears to be sensitive to the proton radius to one that is not sensitive to it, then the radius can be calculated. However, this requires physicists to know all the other effects that influence the position of the states.

In ordinary hydrogen, where one electron whizzes around the proton, the influence of the proton radius is very small because the lightweight elec-
tron usually hangs out far away from the nucleus. In an exotic variant of the element, in contrast, in which a muon, rather than an electron, orbits the nucleus, the effect is far greater.

Physicists produce muonic hydrogen at the Paul Scherrer Institute in Villigen, Switzerland, where they can use the world’s strongest muon beam. The muons come about when protons are shot at a carbon disk in a particle accelerator. Using magnetic fields, the researchers direct the muons into a vessel containing hydrogen gas, which halts the exotic elementary particles. Some muons are captured by hydrogen molecules, displace their electrons and form muonic hydrogen atoms.

Now physicists have to step up the pace with their laser experiments that reveal the energies of the states, as muonic hydrogen remains in the state they need for their experiments for only one microsecond. But the haste pays off: muonic hydrogen is ideal for measuring the proton, and for other experiments, as well, because muons, like electrons, carry a negative charge but are around 200 times heavier.

Due to their greater mass, muons are located closer to the nucleus and are thus more sensitive to the proton radius than are normal electrons. This makes it possible to determine the charge radius with great accuracy – or in any case more accurately than previous experiments permitted, which had put the proton radius at approximately 0.88 femtometers: spectroscopy of normal hydrogen and electron scattering measurements. For the latter, scientists shoot electrons at hydrogen nuclei and observe how they are deflected by the protons.

THE MUON EXPERIMENTS DISREGARD EXOTIC SPECIMENS

What favors the measurements on muonic hydrogen is the fact that they are more than ten times more precise than the results of the spectroscopy on normal hydrogen and the electron scattering. And the more precise a measurement is, the more reliable it is considered to be. Moreover, physicists have since discussed – and excluded – some of the potential systematic errors of the experiments with muonic hydrogen. Some skeptics had speculated, for example, whether Pohl’s team might, without realizing it, have observed negatively charged muonic hydrogen ions that contain a muon and an electron, or molecules composed of two protons and a muon. However, physicists from Paris performed calculations that have since undermined the basis for this suspicion: even if both of these exotic entities are created, they don’t remain stable long enough to permit examination.

In the meantime, the team working with the Max Planck physicists used spectroscopy of muonic hydrogen to measure not only the charge radius of the proton, but also the magnetic radius. The magnetic radius indicates the region in which the magnetization is distributed. This results from the spin of the proton – that is, from the fact that the charged particle is constantly rotating about itself. The electrical and magnetic radius needn’t necessarily be the same size. While the charge radius describes the space in which the charge is found, one can imagine the magne-
The proton radius puzzle: New measurements with the elastic electron scattering from Mainz (Germany) and the US establish the charge radius of a hydrogen nucleus at about 0.87 ± 0.06 femtometers, with relatively large error bars (horizontal lines). This value fits very well with the average value of the spectroscopic measurements of normal hydrogen. The spectroscopic results for muonic hydrogen (μp) obtained in 2010 and 2013 have much smaller error bars, but their values, at 0.84 femtometers, are 4 percent lower than the average of all measurements obtained with electron scattering. No explanation has yet been found for this great discrepancy.

The proton radius as the region in which the circulating currents flow that give a proton its magnetic moment.

For the magnetic radius, the researchers now obtain 0.87 ± 0.06 femtometers. This value is currently still so imprecise that the two controversial values of the charge radius fit with it. “What is important is that we actually determined the magnetic radius using spectroscopy of muonic hydrogen in the first place,” says Randolf Pohl. “It will become interesting when we later increase the accuracy.” Only then will the researchers be able to decide whether their method yields a different value than electron scattering for the magnetic radius, as well.

In any case, for the time being, the magnetic radius isn’t causing such a great stir – unlike the charge radius. Even the latter wouldn’t have been an issue if the new measurements had further narrowed the range of the charge radius as indicated by less accurate experiments. However, the fact that they put the radius in a different range altogether raises fundamental questions.

The story takes on added zest when one considers that the contradictory measurements could indicate fundamental gaps in our understanding of the atoms in hydrogen. This is particularly piquant because, of all the elements, hydrogen is the one quantum physicists know the most about. Since it consists of just one proton and one electron, it is, in fact, the atom that they can describe best in mathematical terms. In other atoms with more electrons, they have to rely on approximations. That’s why they use hydrogen to test their theories, and also why many groups around the world are constantly competing to see who can characterize this atom more and more accurately with increasingly precise measurements. They don’t do this out of a sporting ambition but because, in doing so, they have continually made fundamental discoveries – quantum electrodynamics (QED), for instance.

PLENTY OF ROOM FOR AS-YET-UNKNOWN PHYSICS

QED describes how matter – so, for example, atoms – interact with light, and is considered to be exceptionally well substantiated. Still, it seemed, at first,
as if the new, more precise measurements of the proton radius might challenge this theory. Specifically, it would be possible to resolve the mystery of the differing proton radii in electronic and muonic hydrogen if QED were to ignore an effect that has a much stronger impact on the energy states in muonic than in electronic hydrogen. “But this effect would have to be very large,” says Randolf Pohl. “And it is extremely unlikely that such a large effect has been overlooked up to now.”

Even if a shortcoming of QED has since been nearly discarded as a possibility, Randolf Pohl and his colleagues hope that their measurements will point to as-yet-unknown physical relationships. There is plenty of room for such explanations. Some nuclear physicists, for instance, questioned the concept of how the charge is distributed in the proton. The previous models assumed that the charge decreases approximately exponentially at the boundary of the proton. But what if it decreases more slowly? Or has a cusp somewhere? These are legitimate questions, but they haven’t solved the proton puzzle. Experiments with scattered electrons characterize the charge distribution very reliably – and confirmed the established assumption of an approximately exponential decrease.

**AN ELECTRICAL CHARGE DISTORTS THE PROTON**

Another suggestion that is currently quite popular takes a similar direction. “Perhaps the proton is polarized differently than previously assumed when it sees the negative electrical charge of the muon,” says Randolf Pohl: the electrical charge distorts the charge cloud of the proton, and does so all the more the heavier the particle is that pulls on it. Physicists factor this in when calculating the proton radius from their laser spectroscopic analyses. If the corresponding formulas currently don’t correctly account for the polarization, this will be most noticeable in muonic hydrogen.

“What would be most interesting, however, is if our result were to point to a physics beyond the standard model,” says Randolf Pohl. The standard model of particle physics describes all elementary particles and most of the forces between them. It covers most observations very well, but it also has some weaknesses. For instance, it doesn’t explain gravitation. Nor does it answer the question about dark matter, which accelerates the movements of stars but is otherwise practically unnoticeable and therefore hasn’t yet been identified either.

Although the shrunken proton can’t directly be of any help in the search for the mysterious substance, it could generally contribute to expanding the standard model: “It’s conceivable that an as-yet-unknown particle is responsible for the muon being more tightly bound to the proton than we assume,” says Randolf Pohl. The muon then moves about at closer range to the nucleus than assumed. But if physicists aren’t aware of the particle and don’t know
that it forces the muon closer to the nucleus, the proton of muonic hydrogen will appear to them to be smaller than that of electronic hydrogen. As attractive as Pohl finds the thought of having found a door to the world beyond the standard model, he remains realistic: “That isn’t very likely,” says the researcher.

RYDBERG CONSTANT MUST BE DETERMINED MORE ACCURATELY

While theoretical physicists are busy formulating possible explanations, the experimenters are not sitting idly about. “A more precise determination of the Rydberg constant would allow us to verify whether our measurement is correct,” explains Pohl. Physicists use this constant to calculate the different energy levels of atoms and molecules. If Randolf Pohl and his colleagues are right about the smaller proton radius, then also this constant would change – and perhaps a few other physical constants, as well. No other physical constant is known as precisely as the Rydberg constant. If one could use electronic hydrogen to determine it even more precisely, then it would be possible to indirectly verify the result of the proton measurement. Several researchers around the world are working on this, including a group at the Max Planck Institute of Quantum Optics.

In the meantime, Randolf Pohl and his team are also continuing their experiments with muonic atoms at the Paul Scherrer Institute. The researchers will soon perform spectroscopy of muonic helium ions. For one thing, this will allow them to test once again whether the QED models are actually complete. “Helium is better suited for this, because it is easier to observe weaker QED effects in heavier nuclei,” explains Pohl. For another, the measurements on muonic helium are better suited for comparison with the results of electron scattering. “The electron scattering data for helium is more precise,” says Pohl.

A new elementary particle would also have to be noticeable in muonic helium. Then, in helium, there would likewise have to be a discrepancy between the two different measurements of its nuclei. Otherwise, the door to a physics beyond the standard model would close again before it really even opened.

TO THE POINT

- An international team working with researchers from the Max Planck Institute of Quantum Optics measured the charge radius of the proton very precisely for the first time. To do so, the scientists performed spectroscopy of the energy states of muonic hydrogen.
- The results of the measurements on muonic hydrogen differ significantly from the results of the spectroscopy of normal hydrogen and the results of electron scattering, the method that was previously commonly used to determine the proton radius – indicating that the proton is smaller than had been thought.
- The difference between the results of the two measuring methods could indicate that the picture that physicists had of the proton is incomplete. But it could also point to an as-yet-unknown elementary particle.

GLOSSARY

Electron scattering: When an electron is fired at a positive charge, such as a nucleus, the positive charge deflects it. Electron scattering uses this to advantage: the distribution of the charge, and thus its radius, can be deduced from an analysis of the electron paths.

Charge radius: Quantum particles aren’t as precisely delimited as billiard balls – their boundaries are rather fuzzy. The same is true for the charge radius of the proton. It is defined as the radius within which about two-thirds of the positive charge of the proton is concentrated.

Muon: This elementary particle has the same negative charge as an electron. It can thus replace an electron in hydrogen, or also in a helium ion. But since a muon is about 200 times as heavy as an electron, it comes much closer to the nucleus, and certain effects more readily come to light in muonic atoms.

Quantum electrodynamics (QED): This theory describes how matter – atoms, for example – interacts with light. It is considered to be exceptionally well substantiated.
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More than Just Sweet

When they hear the word sugar, the first thing most people think of is candy. Some may also think of diabetes. Peter H. Seeberger from the Max Planck Institute of Colloids and Interfaces in Golm, in contrast, wants to use sugars to develop more effective drugs and vaccines. He hopes his work will benefit primarily poorer countries.

TEXT CATARINA PIETSCHMANN
Photo-reactor for flow synthesis. This method involves piping the reactants through a coiled-up tube and irradiating them with light. Researchers can use it to produce a wide variety of chemical substances.

Peter H. Seeberger has headed the Biomolecular Systems Department at the Max Planck Institute of Colloids and Interfaces in Potsdam since 2009. He is one of the protagonists in the field of glycomics – a branch of research that is trying to get to the bottom of the entire complement of natural sugar molecules. One of the ways in which Seeberger wants to use these molecules, which experts refer to as glycans, is to learn how cells communicate with each other.

Chemically speaking, sugars are compounds that consist of longer or shorter, branched or linear chains of individual sugar building blocks. Some 80 percent of plant biomass on Earth consists of sugars, and the largest proportion by far is made up of the cellulose of plant cell walls, a chain molecule made of glucose.

But glycans don’t just provide plant cells with stability – they are also molecular antennae with which cells can make contact with the proteins of their “neighbors.” Each cell in a human, animal or plant is downright littered with sugars on its surface. Like tiny antennae, the sugar chains coupled to fats and proteins jut out from the surface of the cell. Bacteria and viruses also use these antennae to dock onto.

**GLYCANS AS AN ADDRESS CODE**

Sugars are involved as early as the fertilization of the egg cell. In the nascent embryo, glycans act as a kind of zip code and direct cells to their destination. “It’s interesting that precisely these sugars turn up again in later life,” says Seeberger. “When cancer cells migrate and form metastases, the same address system is used again.”

There are four classes of glycans. First the glycoproteins, proteins to which sugar chains are bound. About 75 percent of the membrane proteins of human cells belong to this class. One (in-) famous example is erythropoietin, abbreviated EPO. This messenger substance stimulates the growth of red blood cells, thus helping cancer patients with impaired blood formation – but also athletes who want to illegally improve their performance.

The second class, the glycosaminoglycans, includes heparin, a blood coagulation inhibitor used all the time in medicine. While its glycan chain consists of 200 to 250 sugars, the sweet part of the third class, the glycolipids,
Glycans have numerous roles in a cell: On proteins and fats of the cell membrane, they constitute important contact points with other cells. GPI anchors, on the other hand, attach proteins in the cell membrane. Glycosaminoglycans are chain molecules composed of repeating disaccharides, such as the blood coagulation inhibitor heparin, or hyaluronic acid, which gives joints and cartilage their stability. Glycans have numerous roles in a cell: On proteins and fats of the cell membrane, they constitute important contact points with other cells. GPI anchors, on the other hand, attach proteins in the cell membrane. Glycosaminoglycans are chain molecules composed of repeating disaccharides, such as the blood coagulation inhibitor heparin, or hyaluronic acid, which gives joints and cartilage their stability.

The different blood groups, for example, are based on these sugar-containing fats. The fourth group is comprised of compounds of fats and proteins with glycans, “GPI anchors.” They attach proteins in the cell membrane.

Glycans have a relatively simple structure compared with other molecules. Back in the late 1800s, German chemist Emil Fischer decoded the structure of individual building blocks of sugar and received the Nobel Prize for this work in 1902. So why has it taken so long to investigate the function of the glycans? “That’s easy to explain,” says Seeberger. “Until recently, there was no fast and reliable technology with which we could analyze and artificially produce sugar chains.”

The glycans get their backbone from ring-shaped sugar building blocks, each consisting of four or five carbon atoms and one oxygen atom. Such rings have large numbers of binding sites. Their biological activity depends on whether two sugars are joined together at the correct position and with the correct physical structure.

Nobody knows how many different glycans exist overall. And there is still a lot of speculation as to whether certain lengths or patterns occur again and again.

Though scientists were already able to multiply DNA in the 1970s, it was 2001 before they were successful with the automatic synthesis of oligosaccharides. Peter H. Seeberger, then a Professor at the Massachusetts Institute of Technology (MIT) in Cambridge, converted an old DNA synthesizer for this purpose. The sugar building blocks are linked together in a similar way to how the DNA building blocks are assembled. Linkage molecules, which act like small eyelets, are bound to a substrate of plastic beads the size of grains of sand. The first sugar is attached to these. Its potential binding sites have protective molecules on them that can be split off. In the next step, the protective cover is removed from the intended site. This is then followed by the next coupling step.

Attach, remove protective cap, attach, remove protective cap – cycle by cycle, he succeeded in attaching one sugar to the next up to a “nine-fold sugar,” a polysaccharide made of nine
sugar building blocks. The synthesizer shortens the time needed for the task from months to hours. The team has since further refined the method and produced more than fifty different sugar building blocks for the machine. Every cycle, every new link in the chain, takes around three hours. The researchers currently hold the world record: chains of thirty sugar building blocks.

The linkage molecules were a critical point, because at the end, the glycans need to be split off from the plastic substrate. The latest version is now a photosensitive molecule.

There was only one problem here: light can’t penetrate into the plastic. But team member Daniel Kopetzki had already solved this problem in a different research project, synthesizing the malaria drug artemisinin. To enable the light to really reach all molecules, Kopetzki wrapped a thin, transparent tube around a small, transparent plastic chip containing sixty LEDs and pumped the reaction solution into it. Using light intensity and pumping speed, the reaction could now be optimally controlled — “flow synthesis” was born. “We can now make the yield of chemical reactions independent of the human factor — that is, the skill of the chemist,” emphasizes Seeberger.

The diameter of the tube through which the sugar is pumped is hardly bigger than the substrate particles. So each linkage molecule really does receive sufficient light and can release the sugar chains attached to the substrate.

**VACCINES MADE FROM SUGAR**

There are currently six sugar synthesizers in the world, four of them in Berlin. Seeberger’s team uses them in conjunction with the flow reactors for various purposes. The 75 team members include immunologists and parasitologists, in addition to chemists, biochemists and engineers, because one focus of Seeberger’s research is vaccines made from glycans.

Three sugar-based vaccines against bacterial infections have already been developed using traditional methods: vaccines for pneumonia (pneumococci), meningitis ( meningococci) and *Haemophilus influenzae* type b. Children in Germany are now routinely vaccinated against all three pathogens. Until now, the glycans have been produced from cultivated bacteria, which makes production complicated and in many cases impossible. In the future, Seeberger wants to produce vaccines by completely chemical means. This will also make it possible to manufacture new vaccines against bacteria that can’t be grown artificially or whose sugars can’t be isolated.

His plan is to artificially produce a glycan from the surface of the pathogen and administer it to lab animals, whose immune system will then form antibodies against it. However, a pure sugar vaccine won’t work, because the immune system of children under two years of age and people over 55 doesn’t recognize it as foreign.

An auxiliary substance, an adjuvant, is required to spur on the immune system. To date, exogenous carrier proteins such as the diphtheria or tetanus toxin have been used for this. But not only do they sometimes trigger strong vaccination reactions, they are also partly responsible for the high price. This is because proteins are sensitive to heat. “More than half of the vaccination costs are swallowed up by the cold chain. This is a huge problem in Africa and Asia.” Coupling the glycan to a certain lipid molecule, in-

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Photos: David Ausserhofer (2)

left-hand page: Left: Peter H. Seeberger heads a large team of several dozen scientists in Potsdam. Right: Daniel Kolarich (standing) investigates the role of glycoproteins, Daniel Varón Silva (third from right) works on GPI anchor glycans, Chakkumkal Anish (second from right) studies the glyco-biology of infectious diseases, and Bernd Lepenies (far right) analyzes the function of glycan receptors of the immune system.

below: Left: Automated sugar synthesis: The synthesizer brings the reactants together at the right time and in the right quantity. Right: Sandip Pasari checks the bottles with the individual sugar building blocks.
Streptococcus pneumoniae isn’t easy to fight with a single vaccination, either. The pathogen causes middle ear infections and, in serious cases, can settle in the brain or lungs. Tens of thousands of children used to die from it every year. The vaccine available today contains 13 different glycans. “Unfortunately, the pathogen has 96 different serotypes, with a correspondingly large number of sugars. The vaccine is therefore not efficacious for all infections,” explains Seeberger. “For two years, ten scientists have been working intensively with this pathogen, and are learning a great deal in the process: some sugar building blocks are essential, and others can be left out.”

Tests for diagnosing disease are another of Seeberger’s research fields. They react to the immune system’s antibodies against bacteria or viruses. The researchers have developed a method for detecting infections with the Toxoplasma gondii parasite, for example. This parasite is transmitted by cats and is widespread throughout the population, but it is dangerous only to pregnant women and people with a weak immune system, for example following cancer therapy.

With glycan tests, it’s possible not only to determine whether a person is infected with a certain germ, but also whether they have ever come into contact with it. Even with those that could be used as a weapon. The group has therefore also developed diagnostic methods for potential biological weapons such as anthrax and the plague bacillus Yersinia pestis.

There is room for up to 10,000 different sugars on small glass chips. “One
A milligram of glycan can coat thousands of chips,” says Seeberger. He was the first to print the sugars onto the chips with a converted inkjet printer. The test itself is then very simple: put a drop of blood on it, rinse and stain – that’s all there is to it. Antibodies in the blood sample now bind to the corresponding sugar molecules and fluorescent proteins cause them to luminesce. Finally, the pattern of light spots reveals the antibody and thus the pathogen.

Other tests are intended to differentiate between healthy cells and cancer cells. Daniel Kolarich from Peter Seeberger’s group discovered that healthy skin cells have different glycans on their surface than do tumor cells. He is now working with dermatologists from Leipzig on a test for malignant skin cancer cells.

Researchers around the world now use Seeberger’s sugar library, which now contains more than 600 different glycans: neurologists from Zurich are using glycans to reduce the effects of strokes, and doctors at the Charité hospital in Berlin trace cancer cells with radioactively labeled sugars.

The pharmaceutical industry initially showed little interest in glycomics, as Seeberger was forced to realize when he was working on the development of a vaccine against malaria. In 2002, it was successfully proven that a glycan is a long-sought toxin of the malaria pathogen. “When we synthesized it and used it to vaccinate mice, three out of four mice survived a subsequent malaria infection.”

In animal tests, they were able to increase the effectiveness of the further improved vaccine candidate to almost 100 percent. The technology to produce the vaccine in large quantities was also available. Yet the vaccine has been put on ice since 2007 because the participating companies felt that the risk of not recouping the enormous development costs was too high. “Industry funds primarily projects on illnesses that occur in industrialized nations, because those are the ones that will later earn them good money. Hardly any profit can be expected from patients in poorer countries,” says Seeberger.

But a malaria vaccine is so desperately needed. Just recently, the vaccine candidate developed by GlaxoSmithKline with several hundred million euros of funding from the Bill & Melinda Gates Foundation had to be abandoned. After several years of development, the vaccine turned out to be not effective enough.

The consequence is that, somewhere in the world, a child dies of malaria every 20 seconds. But Seeberger calculated that only 4.5 kilograms of glycan would be required to vaccinate the 65 million children born every year in malaria-endemic areas. “A vaccination would cost only a few cents per child.” Despite everything, he has not given up on the vaccine, and is campaigning for new funding to develop it further.

Peter Seeberger doesn’t see himself as a do-gooder, but more as a toolmaker. “If we have the knowledge and the technology to change something, we should do it.” But funding isn’t available for him to undertake clinical studies himself, nor is this compatible with the role of the Max Planck Society. But bringing research results as close as possible to the market is.

A few companies have already emerged from the research in Seeberger’s department. One of them is called GlycoUniverse. Doesn’t the name stir up overly large expectations? Peter Seeberger laughs. “No, because the company produces the sugars as tools that will be indispensable for many applications in the future.” So there are sweet hopes for better medicine for people all over the world.

TO THE POINT

- Scientists today can produce polysaccharides artificially. They do this by attaching the individual sugar building blocks to each other in an arbitrary sequence via different binding sites.
- Proteins, fats and other cell molecules often have chains of sugar molecules. These molecules, called glycans, are important signals for cell communication and for the immune system.
- Glycans are important target molecules for more effective and lower-cost drugs, vaccines and diagnostic tests.
A Virtuoso with Molecules

Creativity is as much in demand in research as in music. Nuno Maulide has a wealth of creativity. A chemist working at the Max Planck Institut für Kohlenforschung (Coal Research) in Mülheim an der Ruhr, he not only develops new synthetic methods for valuable organic compounds, he also continues to impress people with his piano concerts.

Nuno Maulide closes his eyes. For a brief moment, there is complete silence in the foyer of the Max Planck Institut für Kohlenforschung. The crowd looks with anticipation at the man who has just sat down at the shiny Bechstein grand piano. The pianist lets the corners of his mouth relax and leans his upper body slightly forward. Scientists and administrative staff, trainees and doctoral students – they all await the moment the pianist will begin his performance. Then he plays the first chord, Frédéric Chopin, and the intoxicating music of the Romantic composer fills the room. The foyer of the institute has been transformed into a concert hall.

For Maulide, the concert is already his second presentation of the day. Earlier, the young researcher from Portugal presented his research work at the institute in Mülheim, for which he received the Early Excellence in Science Award sponsored by the Bayer corporation. In its introductory laudation speech, the management board of the Bayer Science & Education Foundation called him a “rising star in chemistry.” Now Maulide is playing some of his favorite pieces from the Baroque and Romantic periods for the more than one hundred guests of the award ceremony, on a grand piano rented for the occasion. Piano music and chemistry – these are the passions of the 33-year-old, even if he dedicates decidedly more time to chemistry, not least because he leads a research group at the Max Planck Institut für Kohlenforschung.

It has been a short and steep rise up the scientific career ladder for Nuno Maulide so far. After completing a master’s and a doctoral degree under István E. Markó at the University of Louvain in Belgium, he spent a year in postdoc-

The chemist’s other passion: Before Nuno Maulide began his scientific career, he studied piano.
α-pyranone as an achiral precursor substance

Maulide found a way to create three-dimensional cyclobutenes from α-pyranone, a flat precursor substance, using light (hv) and reagents called nucleophiles (Nu). Since these compounds exhibit special three-dimensional structures referred to as chiral, and can be provided with various chemical functions by the nucleophiles, they are ideally suited as raw materials for the preparation of biologically active substances.

I’m interested in the fundamental understanding behind chemical reactions. How does the reaction proceed – and why?

Maulide originally had completely different plans. “I was sure for a long time that I wanted to become a musician,” he says. He began playing at the age of nine and later studied at a renowned music conservatory in Lisbon. “Nevertheless, my parents weren’t exactly pleased when I revealed my plans to become a professional musician.” His parents didn’t like the thought that their youngest son might have difficulties finding a permanent job as a musician.

Maulide’s father and mother both hail from Africa. He comes from Mozambique, she from the island of São Tomé, both former Portuguese colonies. His parents met as medical students at the University of Coimbra. “Both of my older siblings did something sensible professionally – and then I come along and want to be a musician!”

STUDYING PIANO WAS A SOLITARY AFFAIR
In the end, Maulide enrolled in music studies at the University of Lisbon. “And my parents supported me every step of the way.” He continually gave piano instruction during his studies. Teaching, also part of the everyday activities of a group leader in the Max Planck Society, was already close to his heart. “But I soon noticed that studying piano is a solitary activity – it’s just you and the instrument,” he says today. He took up studies in chemistry after a year – and found in organic chemistry a subject for which he developed just as great a passion as he has for music. “There’s no point doing something if you can’t do it with passion.”

For that reason, Maulide pursues only those chemistry topics that really interest him – but there are many of those. Besides cyclobutenes, he is currently working with sulfur compounds and with lactones. One of the ways a lactone is formed is when a molecule includes both a carboxy group – the characteristic of an organic acid, such as acetic acid – and a hydroxyl group – the characteristic structural unit of an alcohol – and these two chemical groups bond together to form a lactone linkage.

Nuno Maulide’s research group succeeded in developing a new synthetic procedure to prepare lactones, thus facilitating the manufacture of certain organic substances that chemists simply couldn’t prepare before. In the future, these substances could play an important role in the manufacture of aromas and scents.

Looking back, he says that none of his projects have run as originally planned. Nevertheless, success came quickly. And Maulide’s research interests are far from exhausted by cyclobutenes, sulfur compounds and lactones. “I have a lot of new ideas. And none of them have anything to do with the projects we are working on at the moment,” he says, laughing.

MAULIDE CONVEYS A PASSION FOR SCIENCE

A few days after the award ceremony, Nuno Maulide enters a small hall in the older building of the Institute in Mülheim. Most of the analytical departments work in this building, and it is where the doctoral students and trainees are taught. It has the smell of blackboard erasers and classrooms. It is early morning, yet Maulide shows no trace of sleepiness. There are already 15 junior scientists in the room waiting for their boss.

It’s time for the weekly group seminar. Time for the research team to share and discuss the latest results on their projects, as well as everything else going on inside and outside the group. This time, Maulide has a stack of copies of the Max Planck Journal with him. “There’s someone in here you might know,” he says, waving one of the copies in the air, and laughs. One of his doctoral students wrote a book review for the current edition. He wants the others to see it. “For me, the atmosphere and cohesion of my group are incredibly important,” stresses Maulide, who describes himself as a very social person.

This camaraderie, the teamwork and the joy of teaching are also some of the reasons that brought Maulide to chemistry. He especially wants to convey to his students a passion for science, and for his field of organic synthesis. It doesn’t matter whether that happens in informal group seminars at the institute or in a lecture at one of the neighboring universities. Whether in the seminar or the lecture hall, his complete attention is dedicated to his students and junior scientists. He listens to them, taking notes. He jumps from his seat now and then and writes something to think about on the board, often only fragments of molecules. He gives praise and encourages the students to acknowledge and accept one other. “Teaching and instruction have always given me a lot of pleasure,” says Maulide. “And it is also what I particularly like about working as a group leader.”
However, becoming accustomed to the position of being a group leader wasn’t so easy at the beginning. “No one knew me and I had no staff.” A small team quickly became established, though. “Still, I first had to learn that my decisions could influence the scientific careers of other people now and that I carry a lot of responsibility for my students,” says the researcher. “You suddenly grow up and realize that young people are entrusting you with their professional futures. I’m the youngest in my family in Portugal, the little brother. Here I feel like the older brother of my students.”

When recruiting new “family members” to the research group, one thing is especially important to Maulide: interpersonal relations. “Only people I like to spend time with work in our team,” he emphasizes. “Because it means a lot to me that we can trust each other and are loyal to one another.” Consequently, before he hires a new doctoral or postdoctoral student, every candidate is also introduced to the other students in the group – “the kids,” as he calls them.

The student-teacher relationship is equally important to Maulide when he is the student, such as when Christel drops by one afternoon. Christel is his German teacher. “Christel came to visit once, and she seemed the ideal person right on the spot,” he says, describing his first meeting with the professional translator from the Ruhr area.

A pleasant, concentrated working atmosphere prevails in Maulide’s simply furnished office where the German les-
son takes place, just like in the seminars. Nuno Maulide, who has just described a complex synthesis process to his students as a university lecturer, suddenly slips into the role of student. Today’s language lesson is all about finance.

STARTING A NEW CHAPTER IN LIFE IS PAINFUL

With enthusiasm that can hardly be contained, the researcher soaks up the vocabulary on his notepad, even conscientiously learning frightful German compound nouns like *Lastschriftverfahren* (direct debit procedure) and *Einzugsermächtigung* (direct debit authorization). As he ponders a decision, he plants his elbows on the desk and buries his face in his hands – only to rise up again smiling as the answer comes to him.

“If I want to work with German students, I need to be able to speak German well,” says Maulide. “That is also important for my students’ knowledge of chemistry,” he explains later. He sees the biggest difference between his previous stations in life and his current job in the teaching activities and staff responsibility as leader of a research group.

A conference in Bordeaux proved to be a decisive moment in his scientific career. “I met Benjamin List for the first time there,” explains Nuno Maulide. Benjamin List is Managing Director at the Max Planck Institut für Kohlenforschung.

He smiles broadly as he describes this encounter, as he often does when he speaks of things that give him joy and that he recalls fondly. “I had put up a poster about my research project from Louvain. No one seemed especially interested in it.” But then Benjamin List happened by. “I was curious what he would say about my project. So I simply called out: May I introduce you to my poster?” Ben List stopped – and the two researchers began to talk. “We almost missed the next lecture.”

That was in 2005. Four years later, Nuno Maulide began work as a Max Planck research group leader in Benjamin List’s Department of Homogeneous Catalysis. Having just gone to North America a year before, yet another move lay before him. “Of course it’s painful when you start a new chapter in your life. You give up the comfort of familiar habits you’ve acquired. But it’s the only way to personal growth,” says Maulide – and adds with emphasis: “and at the moment, I can’t yet imagine a life in which I no longer continuously seek to grow.”

Maulide is young, ambitious and has already been around the world quite a bit as a scientist. “My home will always be my parents’ apartment in Portugal, though, just across from the Sporting Lisbon football stadium,” he says. However, he also feels at home in his apartment in tranquil Mülheim an der Ruhr. The other stopovers – Switzerland, North America and Belgium – have likewise left traces in his life, be it the impressions and methods he took with him from the various laboratories, or things like fine Belgian chocolates that he brought back with him from European visits for his colleagues in North America. Some boxes of fine Belgian chocolate seashells can still occasionally be found under his coffee table at home.

EUREKA MOMENT IN THE LIBRARY

Maulide’s research is also characterized by always exploring new territory. His work with cyclobutenes certainly resonated throughout the chemical community, though only a few chemists were involved with these compounds back then. “I’m not someone who likes to look around in the same places where everyone else is busy. I prefer to go my own way.”

How did the idea for this project come to him? By browsing the old scientific journals in the library at Stanford. “I love libraries!” exclaims Maulide. “When I have time, I like to look at old journals and the older research work of colleagues.” So it was in 2008 at Stanford, as well. He was comparing older scientific articles with the work.

Maulide’s team is able to attach ylides, compounds containing a formally negatively charged carbon atom and a positively charged hetero atom, such as sulfur (S), to another molecule, such as a ketone (above) or an indole (below), in only a single step. Previously, the process involved at least three steps.

Graphic: MPI für Kohlenforschung

“At the moment, I can’t yet imagine a life in which I no longer continuously seek to grow.”
Maulide modified a known reaction to make lactones (ester rings) in the solvent dichloromethane (DCM) employing collidine (trimethylpyridine) and trifluoromethanesulfonic anhydride (Tf$_2$O) under microwave irradiation. An allyl or allenyl substituent sits at the α-position, directly adjacent to the double-bonded oxygen (O) that is characteristic of a lactone. The compound formed can have various groups ($R_1$ to $R_3$) attached. Nuno Maulide is searching for these and other types of new reactions, which can also lead to new molecules. The molecular model he is peering through here may be such a candidate, because it doesn’t exist yet.

Although his research and position as group leader take up a great deal of his time and energy, he is also re-dedicating himself to piano playing in Mülheim. “For years, the only time I got to play was when I happened by a piano store. I didn’t have an instrument at home in Belgium or North America, so I couldn’t practice regularly.” That changed when he joined the Max Planck Institute in Mülheim. “I had barely moved into my new flat in Mülheim when I rented a piano.” Almost every lunch hour (and many other times as well), Maulide spends time at the piano learning new pieces. “My first great hurdle after I had begun again was the Barcarolle by Frédéric Chopin,” he recounts. “Once I had managed that, I knew I could do anything!” And although he’s a chemist through and through, the piano is more than a mere hobby for him. He is as ambitious with it as he is in the lab during the day, giving benefit concerts for UNICEF and taking part in international competitions for amateur pianists. Last year, he made it to the final round of the prestigious Manchester and Paris international competitions.

“When I sit at the piano, all my cares melt away,” says Nuno Maulide. “I’m alone with the music and the composers whose work I play.” When he gives a concert, he always reveals something of himself, “and much more than during a lecture.” But he would no longer want to trade. “As leader of a research group, I can do exactly what I want and what interests me. I have a lot of freedom and I decide in which direction our next projects go. It’s always important to me that we’re able to analyze everything exactly, especially if the results are unexpected or surprising,” he says and emphasizes, “I would also like my students to develop an understanding of the sort of chemistry we are pursuing here!” And he likes to quote a relevant saying attributed to French chemist Louis Pasteur: “Chance favors the prepared mind.”
DAS GELBE VOM EI

Eine Ausstellung über das Essen


Deutsches Museum

Museumsinsel 1, München · Tel. 089/2179-1 · täglich 9–17 Uhr · www.deutsches-museum.de
The Body
According to Leonardo
In an age of modern anatomy atlases and freely available online body-browsers, Leonardo da Vinci's drawings of organs and body parts done with quill, ink and red chalk may strike us as aesthetically pleasing, yet antiquated. Nevertheless, almost everyone in Germany carries a reproduction of his famous Vitruvian Man with them – on their health insurance card.

Alessandro Nova, Director at the Kunsthistorisches Institut in Florenz, on the other hand, explores Leonardo’s work in the light of the scientific knowledge it generates.

Anyone who examines Leonardo da Vinci’s anatomical drawings will probably first ask themselves to what extent the detailed studies correlate to today’s state of medical knowledge. The depictions seem all too familiar, hardly deviating from the way we see things today. And yet it is important to note that Leonardo was a pioneer in this area and wasn’t able to refer to anything even approximating such graphic visualizations of the inner workings of the human body. Medical-historical research has already extensively compared the knowledge that Leonardo garnered in his day with that of today’s anatomical information, just as his specific morphological and physiological discoveries have long been fully appreciated. The extensive inventory of drawings has also been philologically classified and subdivided into anatomical units such as skeletal system, musculature, nervous system and circulatory system, as well as into today’s established systems, which had not yet been identified in Leonardo’s day. In short, it can be said that the anatomical studies have since been well researched. But perhaps it was just that that motivated Alessandro Nova, Director at the Kunsthistorisches Institut in Florenz since 2006, to take a fresh look at the drawings, not so much by examining their results, but by pursuing the question of what role the process of drawing, the genuine artistic act, played in the generation of scientific knowledge.

VEILED IN THE SHADOW OF IGNORANCE

Giorgio Vasari (1511 to 1574), who paid tribute to numerous Renaissance artists with comprehensive biographies, also turned his attention to Leonardo’s anatomical studies and shed light on his association with the physician and anatomy professor Marcantonio della Torre (1481 to 1511). According to Vasari, “he was one of the first that began to illustrate the problems of medicine with the doctrine of Galen, and to throw true light on anatomy, which up to that time had been veiled in the thick and gross shadow of ignorance. And in this he found marvelous aid in the brain, work and hand of Leonardo, who made a sketchbook with drawings in red chalk retouched in pen and ink: the bodies that he dissected with his own hand were drawn with the greatest diligence.”

Leonardo was at the height of his anatomical research when he met della Torre in Pavia around 1510. The artist had turned his attention to anatomy as early as 1487 in Milan – something that would occupy him for the rest of his life. In the beginning, his investigations into traditional medical knowledge played an important role, at least as far as he was able to tap into such information. After all, it must be borne in mind that Leonardo was self-taught in this area, and could read neither Latin nor Greek. In his day, he was considered to be a man without a classical education, which made it much more difficult for him to gain access to the academic world. This was especially the case with the work of Galen of Pergamon (129 to 199 A.D.), whose doctrines went unchallenged back then. It has been proven that Leonardo’s library contained a copy of Johannes de Ketham’s Fasciculus Medicinae, whose illustrations could at least visually convey Galen’s teachings before an Italian edition was published in 1495. When Leonardo carried out his first corpse dissections, his goal was to understand and verify the centuries-old views of the Greek anatomist and physician; however, his meticulous autopsies brought him increasingly into conflict.
with this handed-down knowledge. A challenging situation arose, which from then on would also be reflected in Leonardo’s drawings. The contradictions he encountered spurred him on to create his own illustrated work that could record his observations and that was ultimately intended to convey no less than a new understanding of the human body.

**VIRTUOSITY WITH CHALK, PEN AND SILVERPOINT**

Leonardo’s encounter with della Torre twenty years later was an important experience for both of them. Leonardo benefited from the exchange with a scientist who had a command of the terminology and rules of the field. Della Torre, on the other hand, was able to make good use of the artist’s extraordinary skills as a draftsman. “However, it would be incorrect to reduce Leonardo’s role to that of an artist who simply placed his eye and hand at della Torre’s disposal,” says Alessandro Nova, whose research picks up here. For, although none of Leonardo’s contemporaries was as adept at drawing with a pen and silverpoint or with black and red chalk as Leonardo was, his anatomical works are anything but an exact mimetic recording of the reality that would have presented itself to anyone who took a close look at the dissected corpses. “Their graphic clarity stems, rather, from an enormous intellectual capacity that previously systematized and grasped that which he observed,” emphasizes Nova. “I call this a ‘manipulation of the visual data’ or the ‘constructed view’. Leonardo masterfully interwove various techniques with each other, such as the assembling of several views to form a new image, the magnification, separation or dismantling of details, and the simplification or fragmentation of physicality to the benefit of a transparent figure.”

Leonardo’s drawing of the female organs, for instance, which he completed shortly before his encounter with della Torre, is an ingenious construction that, although it never be found in reality, nevertheless conveys an image of the morphology and functioning of the female body in a precision that had not existed until then. Leonardo gave due consideration to the graphic figurative modes: while he drew the uterus as transparent, he depicted the windpipe three-dimensionally and fully formed. In contrast, he rendered the heart in a sectional view, and the digestive organs, like the
stomach and intestine, he left out completely in favor of a clearer arrangement. This example clearly shows – and this holds true for most of Leonardo’s anatomical drawings – that they are stylized representations and that it is their high degree of abstraction that ensures their compelling readability to this day.

CLARITY THROUGH THE ART OF OMISSION

In order to illustrate the musculature of the foot and lower leg, Leonardo also made use of the art of omission and simply extracted the entire skeleton, as this would have obscured the structure and organization of the muscles and tendons. By disassembling the spine into its individual parts, he graphically illustrated their structure, which would otherwise have had to be explained at great length. To this end, he enlarged certain bones disproportionately to emphasize their particular functionality; with others, he considered it necessary to show them from various perspectives to facilitate understanding from all sides. “Leonardo himself explained: ‘Through this tersest way of drawing from various perspectives, one provides full and true knowledge of them,’” says Alessandro Nova, quoting the artist and scholar.

This methodical understanding can already be seen in Leonardo’s early anatomical drawings, like the skull studies from 1489. Only the combination of depictions from different perspectives, for example the orthogonal projection and the top view, can provide the viewer with a comprehensive and informative image of the inner workings of the skull. The drawing is thus not a portrayal of the skull, but a symbol that can’t be seen in this form in reality. Furthermore, Nova can convincingly attest to the model-like character of such an assembly by comparing Leonardo’s sectional drawings of the central structure of a domed church: “He adapted the methods of depiction that he was familiar with from his work as an artist for his anatomical studies.”

IN THE COMPANY OF QUARTERED CORPSES

Incidentally, in a new preface to his anatomy treatise in 1509, Leonardo listed what he considered to be the necessary requirements for modern anatomical drawings. “In the process, he explicitly points out that it re-
The drawing featured a density of information that could never have been gleaned from a single autopsy.

quires much more than expert draftsmanship,” says Nova with a grin, in light of Leonardo’s apparent foresight, and goes on to quote Leonardo’s words: “But though possessed of an interest in the subject, you may perhaps be deterred by natural repugnance, or if this does not restrain you, then perhaps by the fear of passing the night hours in the company of these corpses, quartered and flayed, and horrible to behold. And if this does not deter you, then perhaps you may lack the skill in drawing essential for such representation, and even if you possess this skill it may not be combined with a knowledge of perspective, while if it is so combined you may not be versed in the methods of geometrical demonstration, or the methods of estimating the forces and power of the muscles; or you may perhaps be found wanting in patience so that you will not be diligent.”

DRAWING IS A COGNITIVE ACT FOR LEONARDO

Leonardo thus deliberately edited his drawings and constantly worked on improving the forms of representation. As a natural scientist, he penetrated the surface of the body, delving into the interior while dissecting it. As an artist, through the medium of diagrams, he again returned to the body as a whole, which he pieced together anew from the information he considered important. His drawing features a density of information that could never have been gleaned from a single autopsy. Only several dissections finally generated the “data” that flowed into a collective representation and yielded the overall image. As a result, by pondering over the way to arrive at the best depiction, Leonardo simultaneously attained a deeper understanding of the object. “As such, for him, drawing is not a reproductive, but a cognitive act,” explains Hana Gründler, who is working with Alessandro Nova on this project. “In his drawings, Leonardo doesn’t simply represent “fixed”

LEONARDO DA VINCI AND ANATOMY

Leonardo da Vinci, born near the town of Vinci in 1452 as the son of a notary, went to Florence at the age of 17. There, he was apprenticed to the sculptor and painter Andrea del Verrocchio. It was here that he completed the first paintings done by his own hand. In 1481, he was commissioned by the monks at San Donato for an altarpiece showing the adoration of the magi. After this, he moved to Milan and entered the services of the regent Ludovico Sforza, who would later become duke. Over a period of many years, Leonardo planned and developed a monumental equestrian statue in honor of Ludovico’s father, Francesco Sforza. In 1494, however, the duke sent the bronze that was intended for the monument – the Italian wars had begun – to his brother-in-law, Ercole d’Este, in Ferrara, sealing the fate of the statue.

In 1489 and 1490, while extensively exploring the movement patterns of the horse, Leonardo worked on his first anatomical drawings of the human figure, including his famous skull studies. At the same time, he produced the first concept for an anatomical primer. In 1495, Leonardo began work on The Last Supper; in 1499, he left Milan. In 1503, he was commissioned with the painting of the Battle of Anghiari in the Palazzo Vecchio in Florence. During this period, he also painted his portrait of Lisa del Giocondo, the famous Mona Lisa. This was followed by several journeys between Milan and Florence, during which time da Vinci dedicated himself to the tomb of general Gian Giacomo Trivulzio, which was to be crowned with a life-sized equestrian statue. This project, too, was never realized.

Parallel to this, in 1506, he again took up his anatomical research; in Florence, around 1507/1508, he produced groundbreaking drawings based on his dissection of a 100-year-old man. In 1509, Leonardo altered the former concept for his treatise on anatomy. In Pavia, he worked closely together with anatomy professor Marcantonio della Torre, who profited from Leonardo’s extraordinary skill as a draftsman. Starting in 1513, he spent most of his time in Rome, where he continued his anatomical studies at the Ospedale di Santo Spirito. Upon invitation of the French King François I, he traveled to France in 1516, where he lived in the Château du Clos Lucé until his death in 1519 at the age of 67.

Leonardo’s anatomical drawings have been part of the Royal Collection in England since 1590 and are stored in the Royal Library at Windsor Castle. Leonardo bequeathed all of the drawings and manuscripts to his student Francesco Melzi. After Melzi’s death, they were acquired by sculptor Pompeo Leoni, who bound the individual drawings into albums. The portfolio in Windsor harks back to one of these albums, which was auctioned in Madrid in 1609 after Leoni’s death. They are now completely accessible through an Internet database: www.royalcollection.org.uk/microsites/leonardo/. Facsimiles were already painstakingly edited and annotated by Kenneth Keele and Carlo Pedretti in 1979/1980.
knowledge. It is rather the act of drawing itself that sets free renewed reflections about what is being drawn. This, in turn, leads to a modified view of the research object.” Gründler continues: “The processuality in the acquisition and generation of knowledge also becomes visible in the numerous corrections and improvements that have been identified in the drawings.”

NEW OBSERVATIONS VERSUS ANCIENT KNOWLEDGE

Of course, Leonardo’s research began with nature studies, which are what gave him cause time and again to undertake the complex efforts required for performing autopsies, whether in Milan, Florence or Rome. Through empirical studies, he succeeded in revising traditional scientific representations, and a brief look at the illustrations in Ketham’s book is all it takes to appreciate the progress in Leonardo’s drawings, which denote a new epoch in the history of the depiction of the human body. “However, on occasion, he didn’t completely break with tradition,” stresses Nova, citing the studies in which Leonardo and della Torre turned their attention to the heart and its ventricles. While, on the one hand, they made the pioneering discovery that the heart’s system included four – and not just two – ventricles, on the other hand, Leonardo’s drawings of this, which recorded their discovery, depicted the heart’s septum as porous and permeable for blood, which he could not have observed on an exposed heart. “He could only have taken the hypothetical existence of these pores between the ventricles from the literature of the times. The precision of new observations here still collides with the fictions of conventional knowledge as it was imparted in Galen’s teachings,” concludes Nova.

A MERE FOOTNOTE IN THE HISTORY OF MEDICINE

Although the drawings are at the heart of Nova’s research, they can’t be fully understood and analyzed without the accompanying texts that Leonardo added in his famous mirror writing. Text and image form an inseparable whole. From a very early stage, Leonardo planned to publish the results of his dissections in a richly illustrated work with the title De figura umana – “of course, it’s a pity that, as with so many of the projects in his life, he was ultimately unable to bring this undertaking to...
The study of the human body was far more than an empirical-scientific project for Leonardo.

completion,” Nova finds. This is why there is only the occasional reference to Leonardo in today’s history of science and medicine. Only the written elucidations make it possible to explain functional correlations and communicate the primary morphological observation from a physiological perspective.

**FINDINGS DRAWN UP IN DIALOG FORM**

To this end, over the decades, Leonardo even altered the concept of his treatise. While, in 1489, he assumed there would be a tight, balanced synthesis of words and images, in which, however, the drawings would ultimately have predominated, he decided, starting in 1509, to draw up the results in dialog form, which was standard for many written works during the Italian Renaissance, and which could better express doubts, opinions and unresolved issues. Leonardo came to recognize that one could limit oneself to the medium of drawing only “if it were possible to observe all of the things that are depicted in these drawings in a single figure. But it is better to render and describe.” “In the end, it was another physician who profited from Leonardo’s achievements,” says Alessandro Nova. “It was Flemish anatomist Andreas Vesalius, who, in 1543, was the first to publish an illustrated anatomical work based on dissections of the body: the compendium De humani corporis fabrica. But it is believed that he may have known Leonardo’s drawings.”

The anatomical subject matter and the comprehensive accompanying texts go beyond what an art historian usually deals with, making an interdisciplinary approach virtually inescapable. In 2008, a conference was held in Florence that brought together physicians and science historians, philologists and linguists, and last but not least, art historians. The results were published in 2011 in a collection of essays entitled Leonardo da Vinci’s Anatomical World. Language, Context and ‘Disegno’. In this publication, Leonardo’s language is examined and light shed upon the philosophical and literary works that he dealt with and that influenced his texts. It may come as a surprise that, up until that point, and despite the immense body of literature about the life and work of Leonardo, no one had ever turned their attention to the books and treatises written by della Torre, even though he was, for a short time, working in such close collaboration with Leonardo.

**THE SEARCH FOR THE SEAT OF THE SOUL**

As the study of the human body was far more than an empirical-scientific project for Leonardo, the metaphysical aspects can’t be overlooked. “While I thought I was learning how to live, I have been learning how to die,” he once philosophized, and it comes as no surprise that the search for the seat of the intellect, the soul and the emotions repeatedly accompanies his anatomical studies. The encounter with a 100-year-old man in Florence around 1507/1508 with whom Leonardo spoke shortly before the man’s death and whose body he then dissected induced him to look for traces of dying in the specific anatomy of the deceased. Since, in those days, the process of dying was particularly associated with agony and suffering, the tranquil passing away of the old man had strongly impressed Leonardo.

In the meantime, Alessandro Nova has also begun to turn to other scientific areas in his exploration of Leonardo’s drawings. To this end, he invited young scholar Rodolfo Maffeis to join him in conducting research into Leonardo’s studies concerning light and astronomy. In contrast to the anatomical drawings, the astronomical sketches haven’t been historically-philologically examined, meaning that they must first be classified and embedded in the knowledge context of the time. Moreover, 2011 and 2013 saw two further conferences devoted to Leonardo’s optical studies and to his concept of nature. “When it comes to optics, we also encounter the typical triad: appropriation of traditional knowledge, contraposition of his own experiments and observations, and recording of the results in texts, sketches and drawings,” says Nova, reporting on the first results. As with anatomy, optics preoccupied Leonardo his entire life, so that it isn’t far afield to interpret his meticulous scientific studies as a permanent subtext to his artistic accomplishments.

Or did they even constitute the main text? The further exploration of the interrelationship between art and science, which, in the past, were very closely tied to each other, could offer vital impulses to research into Leonardo da Vinci. Thanks to Alessandro Nova, this interrelationship has finally found a bastion at the Kunsthistorisches Institut in Florenz.
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Forschung & Lehre
ALLES WAS DIE WISSENSCHAFT BEWEGT
Almost no other research field generated insights as exciting as those produced by molecular biology in the decade from 1950 to 1960. Some of these results were attained at the Max Planck Institute for Virus Research in Tübingen, where Alfred Gierer investigated what it is that makes viruses infectious.

Niels Bohr, Werner Heisenberg, Erwin Schrödinger – many of the most renowned physicists from the first half of the 20th century were also great philosophers. From the end of the Second World War, however, if they wanted to be successful in their chosen fields, researchers were increasingly forced to specialize. As a result, it has now become impossible for them to excel in more than one scientific discipline – or so one might think.

Nonetheless, there still exist today some individual high-fliers who manage to do just that. These include Alfred Gierer, born in 1929, who studied physics and went on to publish numerous philosophical works. But it was in a third scientific field – that of virus research – that he attained particular renown.

Alfred Gierer was born in Berlin. From 1934 to 1937, he lived in Shanghai, as his father was working there. A physics teacher who was a great admirer of Werner Heisenberg inspired the young Gierer’s interest in science. “When I heard that Heisenberg was coming to Göttingen, I did everything in my power to study there and work at the newly established Max Planck Institute for Physics,” says the now 84-year-old scientist. He wasn’t disappointed – he still recalls the stimulating atmosphere at the institute with great fondness today.

Alfred Gierer completed his doctorate on the subject of hydrogen bonds, which also play an important role in biological molecules, under the supervision of Karl Wirtz in 1953. He then became one of the first post-war German postdoctoral students to be awarded a Fulbright Fellowship. This enabled him to carry out research for one year at the Massachusetts Institute of Technology in the USA. At MIT, the young scientist focused on enzyme kinetics and investigated how the ambient temperature influences the speed at which the body’s detoxification mechanism breaks down alcohol.

When Gierer returned to Germany in 1954, he obtained a new post at the Max Planck Institute for Virus Research in Tübingen. The institute had been established that year from a research group of the same name at the Max Planck Institute of Biochemistry. A new era was gradually dawning in the life sciences: it was the golden age of molecular biology, and the discipline was producing one astounding finding after another.

James Watson and Francis Crick had recently brought their investigation of the mysteries surrounding the structure of the genetic substance DNA to a dazzling conclusion with their legendary article in Nature: the article, which the renowned scientific journal published on April 25, 1953, was entitled Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid.

“The Max Planck Institute for Virus Research was an ideal home for a physicist who had changed fields to work in biology. My boss, Hans Friedrich-Freksa, was a very inspiring and open-minded mentor, and Gerhard Schramm and his department established the tobacco mosaic virus as one of the model systems of the new molecular biology,” says Alfred Gierer. “It was a wonderful experience for me to do science in this early, romantic phase in the life of molecular biology.”

Why viruses, of all things? Exactly one year before the structure of DNA was explained, Alfred Hershey and Martha Chase had used viruses that infect bacteria – known as bacteriophages – to show that nucleic acid is the bearer of genetic information and not proteins, for example, as many scientists had assumed. The nucleic acid is contained in a protein shell in the nucleus of the virus, which doesn’t have many other components. In the case of the bacteriophages, the virus injects the nucleic acid alone into the host cell. This showed how viruses infect bacteria. However, at the time, the researchers were still unable to assess the extent to which this mechanism could be applied to animal or plant victims of viruses.

The actual existence of viruses unfolds within animal, plant or bacterial cells. When viruses infect cells, they reprogram them so that they produce the virus nucleic acid, the virus shell and the other virus proteins. When sufficient components have been pro-
The scientist from Tübingen puts his cards on the table. He reclaims the debate surrounding the impenetrable complexity of reality from the philosophers, theologists and mystics. And he officially abandons scientific reductionism, also a product of the excessively narrow, mechanistic world view.«

duced to equip a complete team of viral offspring, they make a bid for freedom, bursting the cell that has provided them with such vital services. This causes lesions in the organs whose cells are involved – and gives rise to the typical symptoms of the viral disease in question.

The experiments begun by Alfred Gierer and Gerhard Schramm around 60 years ago at the institute in Tübingen made a crucial contribution to elucidating this cycle. "We wanted to find out which components of the virus trigger the infections," explains Alfred Gierer. The researchers worked with the very first virus to be described, the tobacco mosaic virus. Apart from tobacco plants, this virus also infects pepper and tomato plants with tobacco mosaic disease, a pest that once decimated entire harvests.

Gierer and Schramm delicately separated the virus’s protein components from its nucleic acid ones and swabbed some tobacco leaves with a solution containing intact viruses, and others with a solution containing its nucleic acid. The result: 0.2 micrograms of viral nucleic acid caused as much damage to the leaves as 0.2 micrograms of intact viruses. The nucleic acid solution didn’t contain any proteins that could be involved in the biological activity. With these experiments, the scientists demonstrated that the ability to infect plants is due to the nucleic acid and that this is therefore the virus’s genetic substance. This finding was published in NATURE on April 14, 1956.

Why 50 times more free nucleic acid was needed to trigger the same effect as the intact viruses was, initially, something Gierer and Schramm could only speculate on. Just one year later, however, Alfred Gierer explained the reason for this in a follow-up study: the nucleic acid in the tobacco mosaic virus forms a single, large molecule that is extremely prone to decomposition without the protective virus shell.

Another important discovery followed in 1958: Working with Wolfgang Mundry from the Max Planck Institute for Biology, Gierer found that mutations of the virus can be generated by chemically altering the nucleic acid. The chemical conversion of just one of the 6,000 building blocks of the viral genetic material is sufficient to cause a mutation with a strong biological effect on the infection of tobacco plants: the mutated nucleic acid gave rise to a different kind of lesion on the leaves of the target plant than the original solution.

Following these results, at the invitation of the renowned microbiologist Max Delbrück, Alfred Gierer went to the USA for the second time, this time to the California Institute of Technology in Pasadena. At Caltech, he moved away from virus research and began to study how animal cells produce proteins.

Gierer initially stayed with this topic when, one year after his return to the institute in Tübingen in 1960, he became a Scientific Member of the Max Planck Society and head of a new Department of Molecular Biology. Rapid progress had since been made in this field, and an important intermediate goal had been reached with the unraveling of the genetic code. "The discipline underwent a huge wave of expansion, but the romantic phase was over," says Gierer today. "So why not try something new?"

The scientist was plagued by the question of whether the laws of physics are also fully applicable to biology, and how they can be used to explain the formation of biological structures. Developmental biology was the field that would provide him with the answers he sought. Based on the example of freshwater polyps Hydra, he went on to research the factors that control how organisms assume their structural form and the physical principles that underlie this process.

Alfred Gierer’s shift in focus from the biology of viruses to the biology of development influenced the orientation of the entire institute at which he worked. Accordingly, in 1984, the Max Planck Institute for Virus Research became the Max Planck Institute for Developmental Biology. Over time, Gierer increasingly linked his areas of research with questions concerning the philosophy of science. In 1985, he published his first book, Die Physik, das Leben und die Seele (Physics, Life and the Mind), a work that attracted a very broad media response.

Gierer constantly sought contact with the public. By claiming that “scientists must make science understandable” in an article in the NEU-ULMER ZEITUNG newspaper in 1992, he clearly distanced himself from the image of the academic who withdraws to the ivory tower of the university to focus exclusively on his research.

Today, Alfred Gierer remains active as an emeritus member at the Max Planck Institute in Tübingen. He recently summarized the processes for which the development of freshwater polyps can provide a model of structural formation in a philosophy and history of science study published in 2012. It could, perhaps, be said that Alfred Gierer himself provides an interesting model – of the type of researcher who constantly focuses his attention far beyond the boundaries of his own discipline while doing excellent work within them.
Dinner with Nobel Laureates

At Lake Constance, young scientists exchange views with the best researchers in their disciplines

The Meeting in Lindau is a forum for discussions on research issues for the future and provides scope for personal encounters. The Nobel Laureates even talk about setbacks in their careers.

They are the colleagues who have received the highest accolade that can be bestowed upon a scientist: 34 Nobel Laureates came to Lindau this time in order to pass on their experience to 600 junior scientists from almost 80 countries. The 63rd Meeting lasted one week and was dedicated completely to chemistry. Important issues were the innovative generation, conversion and storage of energy and “green chemistry,” which is intended to be as environmentally-friendly as possible. A large number of doctoral students and postdocs from the Max Planck institutes attended. Eleven of them were invited to the Meeting by the MPG, many others via foundations, for example.

The focus of the conference is on personal encounters. For this purpose, the MPG traditionally organizes an academic dinner with Nobel Laureates from its own ranks. This year, the chemist Gerhard Ertl, Emeritus Scientific Member of the Fritz Haber Institute, was there. Max Planck Director Wolfgang Lubitz from the MPI for Chemical Energy Conversion, who is a Member of the Board of Trustees and thus plays a leading role in the organization of the entire Meeting, was also at the Hotel Helvetia for the dinner with the junior scientists, which lasted for several hours.

On the other days of the Meeting, participants were afforded further opportunities for dialogue: in addition to the 30 lectures by the Nobel Laureates, open-topic discussions were also held. “I had a crowd of more than 100 students. And we had a very lively discussion,” Ertl later said in an interview. After some initial reluctance, the participants then posed personal and critical questions. They wanted to know, for example, what setbacks the scientist had experienced in his career. The 76-year-old Ertl related that he had once erroneously published incorrect analyses. “I was sure it would mean the end of my career. Ultimately, it turned out to not be as big a deal as I had feared.” He used the example to explain that researchers should never allow themselves to be pressured during their research. “Things don’t always work out right from the start. Patience is very important.”

Such genuine answers impressed the attendees. The Nobel Laureates were also taken with the young researchers. “I was impressed by the competence, the curiosity and energy of the young scientists,” said Hartmut Michel, Director at the MPI of Biophysics and 1988 chemistry Nobel Laureate. He sees the Meeting as something positive for all, as it offers the “unique opportunity for the intercultural exchange of knowledge and ideas across several generations, and for setting up networks”.

During the academic dinner of the MPG in Lindau: Chemistry Nobel Prize Laureate Gerhard Ertl and Max Planck Director Wolfgang Lubitz (2nd row left) with junior scientists.
What have you taken home with you from the Meeting in Lindau?

**Tobias Zimmermann, 27, doctoral student at the Max Planck Institute für Kohlenforschung (Coal Research), Mülheim**

I really enjoyed the academic dinner held by the Max Planck Society, because we were in small groups of around 20 and so it was possible to come into direct contact with the Nobel Laureates. Professor Ertl and his wife are very nice! I realized in general during the Meeting that the Laureates are very down to earth people with whom it is possible to talk on equal terms, and who also enjoy a joke. It is comforting to know that Nobel Laureates have to wrestle with the same problems in the laboratory as do other researchers. I found their attitudes really inspiring: for them, science equals passion. I sensed that immediately in the discussions. For them it's not about publications and success, but about the research - and this is the only way to achieve breakthroughs for which Nobel Prizes are then awarded. I was especially impressed by the Israeli physicist Dan Shechtman, who had to fight for a long time until his views were recognized - that certainly made an impression. It's phenomenal how much he believes in his research. This fits well with what Serge Haroche shared with us: “You need trust and time.”

**Karl-Heinz Dostert, 27, doctoral student at the Fritz Haber Institute of the MPG, Berlin**

I found it remarkable that the Nobel Laureates frequently think outside the box of their current research and get involved in major societal issues. Steven Chu, for example, physics Nobel Laureate and former US Secretary of Energy, made some very pointed remarks about climate change, and in a language that could be understood by a wide audience. In the Presentation Skills workshop I also noted how experienced Nobel Laureates deal with the public. I was able to learn a few things by observing them. If I ever get the opportunity to present my work during the “Long night of the sciences,” I would now do many things differently. One important point: for us, science is quickly taken for granted, because we are deeply involved in our field. It is important to put ourselves in the shoes of non-scientists. Then we’ll be able to better explain our work. The academic dinner held by the Max Planck Society was very good for making contacts. We were of course from different institutes and were able to get to know each other. It was a good starting point for getting together again during the course of the Meeting and talking further.

**Vera Krewald, 26, doctoral student at the Max Planck Institute for Chemical Energy Conversion, Mülheim**

The week was overwhelming. I particularly liked the panel discussions of the Nobel Laureates, especially the one on the topic “Why communicate?,” with Simon Engelke, Walter Gilbert, Brian Kobilka, Harry Kroto, Ada Yonath and Beatrice Lugger. They made it clear that we as scientists have a social responsibility and that we must also be good at communicating our findings. I was surprised how easy it was to strike up a conversation with the Nobel Laureates. There were no obstacles whatsoever. During the rounds of discussions in the afternoons, in particular, you could simply ask questions, even several. It is comforting that research setbacks are completely normal, even for Nobel Laureates. Their message to us: what you must do is to quickly get back on your feet again. It was also great to make contact with many other chemists who are undertaking research in similar projects. I am working on the dissociation of water and was able to discuss this on numerous occasions. I even met somebody from the US with whom I will soon collaborate on a project.
A Celebration of Life

In Dresden, an institute becomes a theatrical stage – for everyone involved, an experiment that is a rousing success

“Ziffer, Zelle, Zebrafisch” (“Cipher, cell, zebrafish”) poses questions, lots and lots of questions – about what life actually is, and the role that science plays in it. Answers to these questions come about as if by chance; answers that long remain in the memory, thanks to the play’s strong visual language.

Shakespeare is history. Vineeth Surendranath made a hobby of roles like Macbeth when he lived in India. Now the 34-year-old scientist is conducting research for his doctoral thesis at the MPI of Molecular Cell Biology and Genetics in Dresden and, in his spare time, appears on the stage as what he really is: a quintessential scientist who poses questions, experiments, experiences setbacks in the process and nevertheless makes progress. “It’s great that this becomes clear in the play and that the audience gets an idea of how we work, what we think, and what spurs us on,” he says. “Ziffer, Zelle, Zebrafisch” was conceived for children eight years of age and older, and is performed at the Institute itself in a seminar room that can seat an audience of 50. Mainly school classes have thus far attended more than 25 performances, all of which were sold out.

The play is an experiment for everyone involved. For the makers from the Theater Junge Generation (TJG), a theater especially for the younger generation, and for the independent ensemble “Cie. Freaks und Fremde” and its director Heiki Ikkola, who were looking for a change of perspective. For the researchers, whose work is mirrored artistically, and for the audiences who don’t sit at a distance in the orchestra, but in a circle against the wall while the rest of the space is the stage.

The audience is thus directly involved in the multifaceted play whose plot unfolds thanks to the efforts of the actors Ivana Sajevic and Sabine Köhler who take the stage initially as
fruit flies, later become researchers who conduct wild experiments, and repeatedly ask themselves the question: What is life?

And because there isn’t just one answer to this question, they team up with the children to find different ones, and to pose new ones. In the process, knowledge is imparted over and over again. As, for example, when Ivana Sašević, puppeteer at the TJG, brings a clown marionette to life that defines specialist terms like a living lexicon. With terms that children can relate to, this is a good way to teach the researchers’ vocabulary: experiment, model organism – the clown is often part of the action.

He also disappears occasionally, for example when the actors journey to the cell: a red net becomes the symbol for the smallest living unit of all organisms, filled with balloons which represent the cell’s components. The mitochondria, the endoplasmic reticulum and the DNA - everything that plays a central role is introduced and celebrated with live music by Daniel Williams.

While knowledge from the world of science continues to be conveyed in this way, the play, which lasts a bit more than an hour, also turns its attention to knowledge about the world of science. This is where Vineeth Surendranath – who until now has stood silently in the room, reading books, analyzing samples – comes in. Not as a fastidious-serious researcher in a white coat, but casually in t-shirt and jeans.

TOUR OF INSTITUTES PLANNED

In the middle of the play a kind of talk show develops, where the children ask questions, including, for example, why fruit flies and zebrafish, the model organisms at the Institute, are being genetically modified. “We can observe something that is not a person, but yet still find something out about humans. This helps us to be more successful at treating illnesses,” he explains. What should also become clear is that scientists experiment because they are curious. And that: “Experiments are like games, sometimes you win, sometimes you lose.” In other words: They can go wrong.

Vineeth Surendranath must always react spontaneously in his role, and obviously enjoys himself. “I am surprised how profoundly children at this age can already think,” he says, looking back to his performances to date. “Ziffer, Zelle, Zebrafish” is being performed again in November. “The play has received a very positive response and other institutes are interested,” says Florian Frisch, who is responsible for public relations at the MPI and co-initiator of the cooperation. Enquiries are currently ongoing at foundations in order to be able to fund further performances and finance a tour to various research institutions.

Call for Nominations

Max Planck Research Award 2014

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 human and social sciences.

The Max Planck Research Award 2014 will be conferred in the area of natural and engineering sciences in the subject Quantum Nano Science.

Quantum Nano Science

113 years after the foundation of quantum theory by Max Planck, researchers succeed in controlling materials with ever higher precision to realize exotic quantum states. Thus nano structured materials and devices arise, that by exploiting the most bizarre features of quantum mechanics – take discretisation, superposition, entanglement and many body systems as examples - are designed for special purposes. Such phenomena form the focus of the relatively young experimental field of Quantum Nano Science that has emerged at the interfaces of nano science, quantum optics, photonics, materials technology and quantum information.

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 Alexander von Humboldt Foundation. Applications by prospective candidates themselves are not possible. The deadline for nominations is 31 January 2014.

Further information can be obtained from the

Alexander von Humboldt-Stiftung, Bonn (Germany)
www.humboldt-foundation.de/web/max-planck-award.html
E-Mail: ursula.michels@avh.de
Eight MPG scientists were successful in the sixth and last round of the competition for ERC Starting Grants in the 7th EU Research Framework Programme. The MPG now has a total of 66 Starting Grants, which are awarded to aspiring young researchers, and thus ranks third in European comparison, just behind the University of Cambridge with 67 Grants and the French Centre National de la Recherche Scientifique (CNRS) with 117. If the German rankings are taken into consideration since the Starting Grants were first awarded by the European Research Council (ERC), the MPG holds an uncontested first place, ahead of the Helmholtz Association with 28 grants. The universities then follow at some distance.

In the current round, the successful Max Planck researchers were Ellen Backus (Max Planck Institute for Polymer Research), Saskia Hekker (MPI for Solar System Research), Adam Lange (MPI for Biophysical Chemistry), Johannes Letzkus (MPI for Brain Research), Mikko Myrskyla (MPI for Demographic Research), Arne W. Nolte (MPI for Evolutionary Biology), Swetlana Schauermann (Fritz Haber Institute) and Christian Theobalt (MPI for Informatics). They all receive up to two million euros, spread over a period of five years.

Contrary to the ERC’s list of results, the MPG’s statistics do not include Armin Djamei (MPI of Molecular Plant Physiology) and Oriol Romero-Isart (MPI of Quantum Optics) in these statistics; although they submitted their application with the MPI, they are now moving to the University of Innsbruck and the Gregor Mendel Institute in Vienna.
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