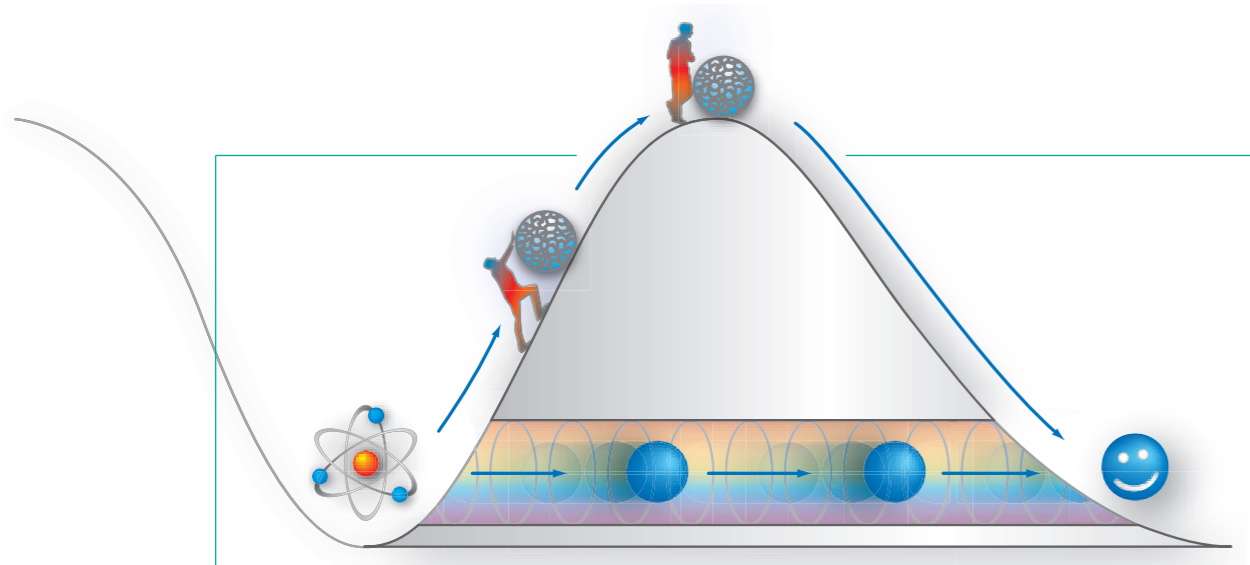




RESEARCH in Brief



QUANTUM PHYSICS

Caught in the Act of Tunneling

We have to climb a mountain in order to conquer it. In quantum physics, however, there is a different way: instead of laboriously climbing over it, objects can reach the opposite side of a hill by simply tunneling through it. An international team of researchers working with Ferenc Krausz from the Max Planck Institute for Quantum Optics has now observed electrons in this tunneling process for the first time. They watched how electrons escaped the attraction of an atomic nucleus. Using ultra-short laser pulses, the scientists proved the existence of discrete levels of ionization, each of which lasts a few hundred attoseconds, or a fraction of a quadrillionth of a second. The results will make a significant contribution to better understanding how electrons move in atoms and molecules. (NATURE, April 5, 2007)

Sisyphus' problem was one of physics. The stone he incessantly rolled up the mountain was pulled back down to the valley again and again by gravity, only coming to a halt at the lowest point because that is where its energy was least. In physical terms, this means that it stopped moving at the minimum of the potential created by gravity. This principle became a curse for the mythical Sisyphus, but it is what holds our world – or more precisely, the atoms of our world – together.

It pulls every particle to the deepest point of a potential – even electrons. The negatively charged particles try to reach the lowest point of the binding potential created by the electrostatic force of the positively charged atomic nucleus. As the electrons move very quickly, they do not collapse into the nucleus, but circulate around it at a respectful distance. They are trapped in an electrostatic

There are two ways to conquer a mountain: In classical physics, you must climb a mountain to get to the other side. Not so in quantum physics: objects can simply move through the mountain horizontally – by tunneling through it.

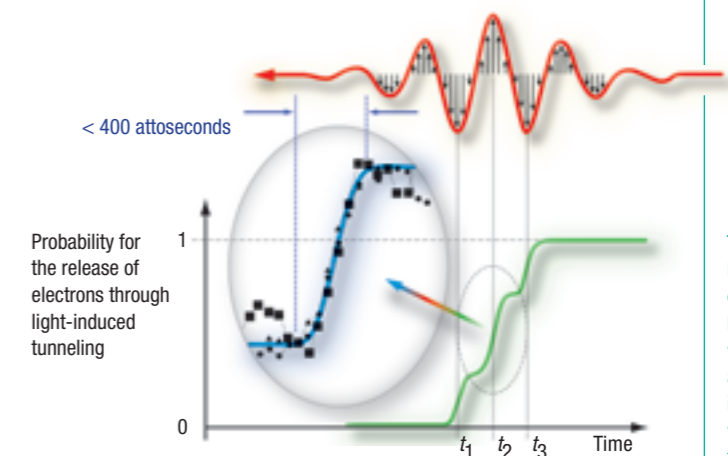
valley by a potential wall. However, the electrons can escape from the valley – and thus from their atom – under the influence of an external force, e.g. that exerted by light. Fortunately for the continued existence of the world, this does not happen often. Quantum mechanics creates a way out for them, permitting them to tunnel through the wall of binding potential formed by the atomic core's attraction and the external force. An international team of researchers working with Ferenc Krausz has now caught the electrons in the act.

After the physicists gave the electrons a push with an attosecond ultraviolet (UV) pulse and lowered the potential wall slightly with a strong red laser field, some of the electrons broke through it. "Our findings confirmed, for the first time in real-time observation, the theoretical predictions of quantum mechanics," says Ferenc Krausz, Director at the Max Planck Institute for Quantum Optics and head of the team of scientists.

According to the laws of quantum mechanics, an electron can tunnel because it is a wave as well as a particle. Therefore, there is a certain probability that it will be somewhere where, according to the laws of classical physics, it should not be – in a potential wall, for example, or even on the other side of the wall. However, the likelihood that a macroscopic object, such as a boulder, would get to the other side of a mountain in the same way is infinitesimally small – which is why no one has yet observed a tunneling boulder. On the other hand, the chances that microcosmic particles will manage to wangle their way through mountains, albeit electrostatic mountains, are pretty good.

However, not only electrons escape the attraction of their nucleus by tunneling. Alpha particles, too, detach themselves from radioactive nuclei in this way, and atomic nuclei tunnel toward each other in the fusion process. Although the tunneling effect is not rare in nature, it has not yet been possible to observe it in real time because it simply happened too quickly. Krausz and his team have now seen it live with the aid of two light pulses: an attosecond UV pulse and an intense pulse of red laser light consisting of merely a few wave cycles. The physicists observed the electron's escape only because they synchronized the pulses perfectly.

There is no instrument that can directly resolve the tunnel effect. Only the end products can be detected – the ions that remain when an electron tunnels out of an atom. The researchers therefore had to use the trick of experimenting with atoms of the noble gas neon, in which the electrons are bound to the nucleus particularly strongly and re-



Tunneling in stages: Each time a wave crest of an infrared laser pulse (red wave) hits the atom, the probability that an electron will tunnel out of the atom increases (green curve, de-tail). There is only a 100-attosecond interval to the next stage – this is how long the electrons need to tunnel.

sist the efforts of the red laser pulse to detach them from the atom. However, when an attosecond flash of UV light hits a neon atom first, it excites an electron and moves it to the periphery of the atom.

The scientists then fire a red laser pulse, containing a series of a few wave crests and troughs, at the atom. Near the wave crest, the electrical field of the powerful red laser pulse depresses the potential wall that is holding the electron in the atom, making it possible for the excited electron to tunnel out.

"With the UV pulse, which lasted only 250 attoseconds, we moved an electron at any time within the red laser wave with attosecond precision to the periphery," explains Krausz. They guided the peak of the UV pulse over the wave crests of the red laser pulse. At the same time, they counted the atoms from which an electron had tunneled out and that had thus become ionized. This allowed them to establish that the electrons tunnel only if the particularly intense wave peaks of the red pulse touch the atom shortly after it was excited by the UV pulse. In this way, they have also been able to set an upper limit on how long the tunneling process takes – less than 400 attoseconds.

"The experiments not only allow us insight into the dynamics of electron tunneling," says Krausz. "We have also shown that the movement of electrons in atoms or molecules can be observed in real time with laser-field induced tunneling." The physicists use these findings to control the movement of the electrons. "In the future, this will allow us to find out how the boundaries of microelectronics can be moved," says Krausz. Optical electronics works more efficiently the more precisely the interaction between light and electrons is controlled. It might even be possible for physicists to develop compact X-ray lasers if they have more influence over the electronic processes in atoms. Such brilliant X-ray sources would allow better images of biological objects or improvements in radiation therapy.

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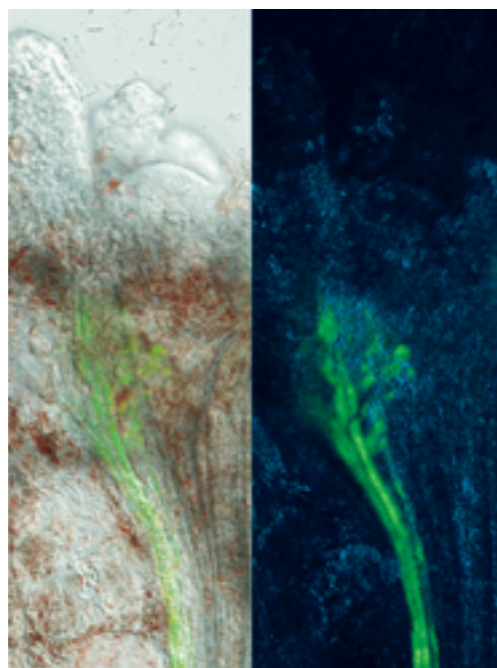
PLANT RESEARCH

The Search for Florigen

Why do crocuses bloom in the spring and asters in the fall? And why are the flowers always found on the tip of the shoots and not anywhere else on the leaves or stems? Plants actually have molecular light sensors in their leaves that measure the seasonal differences in day length. At the right time, usually in the spring, the leaves send a messenger substance as a signal to induce flowering. The question of what this florigen actually is has provided work for generations of botanists. Progress was first seen in the late 1990s and in 2005, and the issue of how the florigen reaches the shoot tip has proved a particularly controversial subject. George Coupland and his team at the Max Planck Institute for Plant Breeding Research in Cologne were able to show that the protein itself migrates (SCIENCE, April 20, 2007) – thereby casting doubt on another publication.

The existence of a florigen was postulated as early as 1936 by the Russian Michael Chailakhyan, who said that flowering was triggered by a hormonal stimulus. It was, however, unclear whether this stimulus consisted of a protein, a nucleic acid or another substance. In the 1990s, Detlef Weigel and his team at the Salk Institute in La Jolla (USA) isolated the long-sought flowering agent at the genetic level: they had discovered the Flower Locus T gene, also known as FT, in *Arabidopsis thaliana*, the mouse-ear cress (Kardailsky et al., SCIENCE 1999). This must be activated in the leaves so that flowers form on the shoot tips. However, the question remained just how FT influenced the genes that finally triggered flowering.

The breakthrough for Weigel and his team came six years later, after they had moved to the Max Planck Institute for Developmental Biology in Tübingen, where they discovered that FT binds to another protein, the FD. This protein controls the activity of genes directly, causing groups of stem cells at the tip of the shoot to develop



The FT protein was tagged with green fluorescent protein (GFP) and observed in the vascular tissue of an *Arabidopsis* (mouse-ear cress) seedling under a microscope. This experiment revealed that the FT protein moves from the leaves to the shoot tips of the plant.

into flowers. FD becomes active only when it binds with the FT protein and, unlike FT, is produced at the shoot tips (Wigge et al., SCIENCE 2005).

As the FT gene is active only in the leaves, the relevant protein must somehow travel from the leaf to the tip so that it can bind with FD. For this, it is possible that it is not the FT protein itself that moves around, but rather the corresponding messenger RNA. This is what Tao Huang, a post doc at the Swedish University for Agrarian Sciences in Umea, and his colleagues believed, having found the mRNA of FT in both the leaves and the shoot tips (Huang et. al., SCIENCE 2005).

In mid-April 2007, however, Swedish plant researchers working with Ove Nilsson retracted this paper after the attempt to replicate the experiment failed. The magazine Science published the retraction in the same issue in which George Coupland and his team presented their latest findings. Working with colleagues from Imperial College in London, the Max Planck researchers had used GFP, a green fluorescent protein from a jellyfish, to track the FT protein.

This allowed the scientists to trace the path of the GFP-FT fusion in *Arabidopsis* from the leaf to the plant tip under the microscope, and to show that the FT protein is indeed formed in the leaves, subsequently traveling through the whole plant to the growing points in the tips, where flowering is induced.

Further proof of the fact that it is the FT protein that travels, and not the associated mRNA, is supplied by an experiment with *Arabidopsis* mutants that do not create an FT protein, as they do not have the relevant gene. These mutants were grafted onto normal *Arabidopsis* plants. The researchers have now observed how the FT protein moves from the lower plant through the grafted FT-free plant, and how flowers then formed. Nevertheless, not all scientists believe that the experiments provide sufficient proof. And so the final chapter in the florigen mystery is yet to come. ●

IMAGE: MPI FOR PLANT BREEDING RESEARCH

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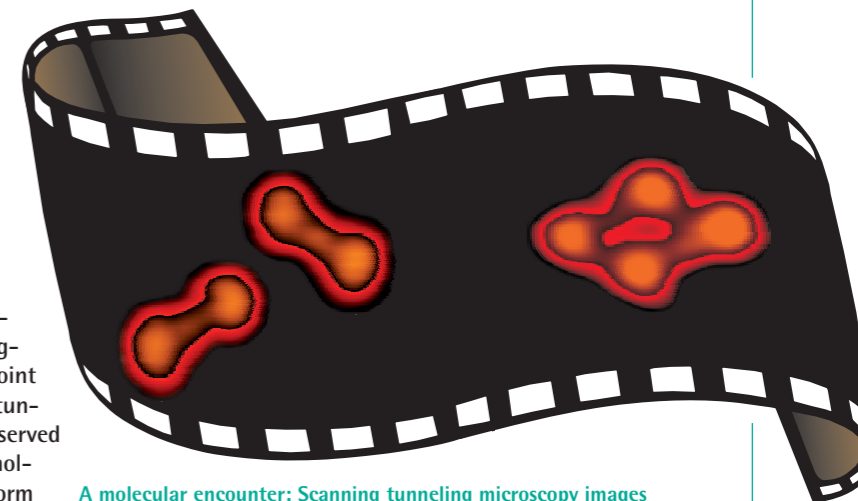
STEREOCHEMISTRY

How Molecules Shake Hands

Life is teamwork on a grand scale: there are more molecules working away hand-in-hand in the human body than there are stars in space. An international team of scientists including researchers from the Max Planck Institute for Solid State Research has now observed how molecules recognize their partners in this joint venture. Using a scanning tunneling microscope, they observed how two chiral dipeptide molecules joined together to form a pair. Like many molecules, these molecules occur in our body in two forms that are mirror images of each other and that, like our right and left hands, cannot be perfectly superimposed onto each other. In order for the dipeptides to be able to form stable pairs and for biomolecules to be able to support life processes, molecules must be able to recognize those with the specific complementary form. The scientists discovered that the molecules modify themselves slightly during this recognition process, like two right hands enclosing each other. (ANGEWANDTE CHEMIE, June 11, 2007)

Some 10^{27} molecules in nearly a hundred thousand different forms make our bodies what they are. Each molecule carries structural information. "This information determines which molecules work together to make the body function," says Magali Lingenfelder, one of the Max Planck researchers involved. For example, biomolecules issue commands that make our muscles contract. They ensure that we use our food efficiently and they allow thoughts to form. The international team of researchers, which was made up of scientists from the Max Planck Institute for Solid State Research in Stuttgart, the Fraunhofer Institute for the Mechanics of Materials in Freiburg and from King's College in London, observed in detail how two diphenylalanine molecules interact as they dock with each other.

The scientists from the Max Planck Institute for Solid State Research made image sequences of this process with a scanning tunneling microscope. The films reveal that molecules only recognize other molecules with the same chirality – that is, an identical structure. Only these matches are willing to join together to form pairs and chains. "This is how nature uses



A molecular encounter: Scanning tunneling microscopy images show how diphenylalanine molecules dock with each other.

information that is inherent in the shape of the molecule to build complex structures," says Magali Lingenfelder.

An important aspect of this information is stored in the chirality. This term is derived from the Greek word for hand and describes molecules that exist in two forms, like hands: the left-handed and the right-handed form. The two cannot be brought into spatial congruence. Using the hand image, either the palms or the backs of the hands are touching, or the thumbs point in different directions. In a handshake, only two right or two left hands fit together perfectly. In exactly the same way, only two molecules with the same chirality form a stable structure.

Chemists refer to this joining of right-handed or left-handed molecules as chiral recognition. "It is highly significant for many processes in our body," says Giovanni Costantini, who was also involved in the study, "because they take place only when the right-handed or left-handed molecules recognize each other. As in a handshake, however, it is not sufficient for two molecules with the same chiral form to meet; they must also adapt themselves to fit to the other. Hands grip only if they close around each other. While the Max Planck scientists were observing the molecular handshake, theoreticians at King's College in London and at the Fraunhofer Institute for the Mechanics of Materials in Freiburg were creating mathematical models of the process.

"The mechanism of molecular chiral recognition helps us to understand the elementary stages of evolution," says Costantini and adds, "It could also contribute to the development of complex artificial materials with specific functions." ●



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ANTHROPOLOGY

How Long Does a Child Remain a Child?

Childhood lasted just as long 160,000 years ago as it does today. This has been established by an international team of researchers from the Max Planck Institute for Evolutionary Anthropology and the European Synchrotron Radiation Facility in France. The scientists found that the teeth of a fossilized *Homo sapiens* child were not any further developed than those of a modern child of the same age; early *Homo sapiens* experienced a long period of growth and development like our own. However, childhood in *Australopithecus* and early *Homo sapiens* lasted hardly longer than that of chimpanzees, which are mature at 10 to 12 years. (PNAS, April 10, 2007)

In purely biological terms, a long childhood has a high price: children cannot feed themselves, they are not prepared for the dangers in their surroundings and they cannot reproduce. "However, children learn social behaviors more easily when they are cared for and taught by adults," says Dr. Tanya Smith, who led the project at the Max Planck Institute for Evolutionary Anthropology. Since modern humans must learn more complex social behaviors than other beings, their childhood lasts longer than that of all other primates. The lengthy period of youth also means that teeth and brains grow more slowly. And this was already

the case shortly after our species developed from its evolutionary ancestors.

This was shown by the international team of researchers using the growth profile of a human who lived 160,000 years ago in Morocco, where the fossil locality Djebel Irhoud is today. Scientists have used the fossilized remains of his teeth to establish that the child was almost eight years of age, and was no further developed than a child of the same age in our time.

This is by no means self-evident: *Homo sapiens*' predecessors, *Homo heidelbergensis* and *Homo erectus*, and the earlier *Australopithecus* species were much more mature at eight years of age. Their youth is believed to have lasted only slightly longer than that of chimpanzees.

"Our results imply that *Homo sapiens* had the cultural and biological characteristics of today's humans very early on in their developmental history," says Smith. "However, if we look at the development of hominids as a whole, these characteristics appear only very late in the record – namely in early *Homo sapiens*."

The scientists deduced the biological age of the fossil from Djebel Irhoud from its teeth. The tooth enamel is marked by thin growth lines like the rings of a tree trunk, which allowed the scientists to reconstruct the timing of tooth growth and the age at which the incisors pushed through from the jaw. This age provides an orientation point from which it can be established how quickly a human grew – even millions of years after his or her death.

However, it is possible to find out precisely how long a tooth had been growing only from the inside of the enamel, since that is the only place where the microscopic daily growth lines can be seen. It is not easy to look at this area without destroying the enamel, but it is now possible thanks to Dr. Paul Tafforeau, a scientist at the European Synchrotron Radiation Facility in Grenoble, who developed a method using microtomography. Tafforeau uses synchrotron X-rays to create three-dimensional images of the very fine structures of the enamel without damaging it. The research team compared the structure of the Moroccan child's 160,000-year-old enamel with that of modern children and other fossil species. "Traditionally, fossils have revealed how humans were constructed anatomically," she says. "Now, using the record of daily tooth growth, they have allowed us to read the history of a human."

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Scientists reconstructed a virtual set of teeth from a fossilized jaw. The growth rings on the enamel can be seen in the background.

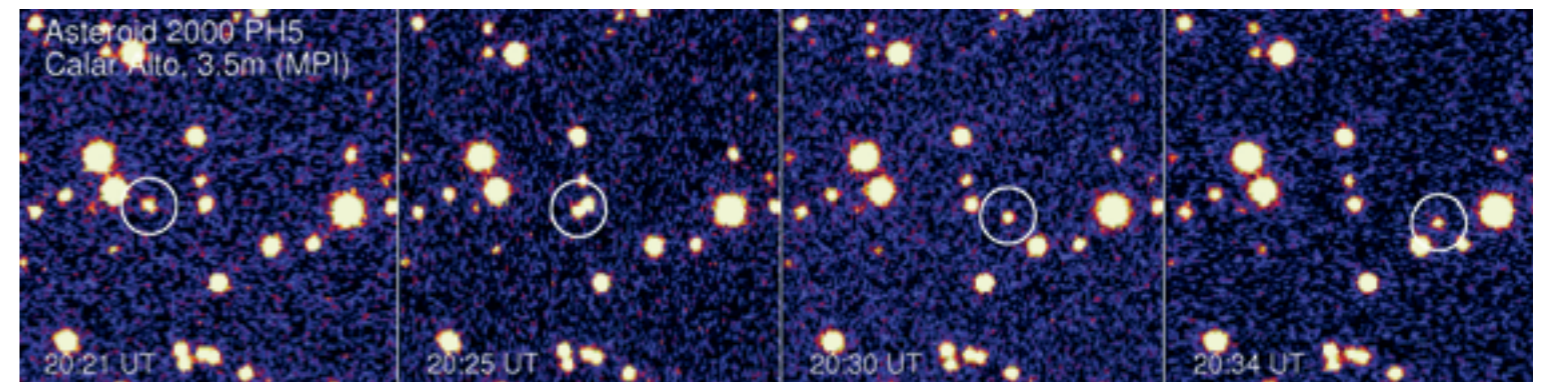
IMAGE: PNAS, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES, USA

ASTROPHYSICS

Light Puts Asteroids in a Spin

Rays from the Sun have never been seen to start a stone rolling on Earth. In space, however, things are a bit different: there, astronomers from Europe and the US, including Hermann Boehnhardt from the Max Planck Institute for Solar System Research, have now shown that light from the Sun exerts a force on 2000 PH5, a small asteroid not far from the Earth. The force, although very weak, is sufficient to make the asteroid rotate one millisecond faster each year. They have measured the Yarkovsky-O'Keefe-Radzievskii-Paddac effect (YORP for short), which has been theoretically predicted by astrophysicists for some time already. (SCIENCE EXPRESS, March 8, 2007)

"However, the torque is so small that it was not previously possible to observe the YORP effect," says Hermann Boehnhardt. Now, however, the research team with which he has been working has succeeded in doing this for the first time. The scientists observed the asteroid repeatedly over five years through optical telescopes, including the 8.2-meter Very Large Telescope Array and the 3.5-meter New Technology Telescope at the European Southern Observatory in Chile, and the 3.5- and 2.2-meter telescopes in Calar Alto, Spain. They calculated the speed of rotation from the rhythm with which 2000 PH5 revealed its lighter, then its darker side. "The acceleration tallies quite precisely with the theoretical predictions," says Boehnhardt.



Small asteroids generally bear very little similarity to a sphere. Asteroid 2000 PH5, for example, races around space in the form of a flat piece of rock, approximately 120 meters square and slightly less than 60 meters high. Furthermore, bulges distort its symmetry and its surface is made up of different types of stone. It is not an attractive sight, but these characteristics, and its short rotation period of currently 12 minutes, make it a suitable candidate for measuring the YORP effect: a torque created by the Sun's light that makes the asteroid gradually rotate faster.

The effect is created by the tiny recoil effect on a body when it is illuminated by light and radiates thermal light back. However, the YORP effect can be observed only for small bodies in space that are not spherical and that have an irregular surface. Due to its irregular shape, some parts of 2000 PH5 heat up more than others and also emit more warmth as infrared light. The same applies to visible light: some areas of this cosmic rock reflect the light better than others, which means that a number of them recoil more than others. All in all, this results in a torque that gives the asteroid a little more spin year after year.

Keeping an eye on the asteroid 2000 PH5, photographed with the 3.5-meter telescope at Calar Alto in Spain. The researchers use the fluctuations in its brightness to calculate its rotational speed, which is increasing steadily under the influence of the Sun's radiation.

According to this theory, 2000 PH5 rotates a thousandth of a second faster every year, which could eventually make it the fastest-rotating asteroid in the solar system. If the spin continues to increase at this rate, in 35 million years, 2000 PH5 will take just 20 seconds to spin once around its axis.

But rather than setting a record, this acceleration could result in a premature end for 2000 PH5 – when its momentum causes it to fly apart. "The YORP effect may make a number of asteroids rotate so fast that they break up," says Hermann Boehnhardt. This could also be the reason why astronomers have yet to find an asteroid that takes fewer than 80 seconds for one rotation.

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CLIMATE RESEARCH

Feedback Effect in the Greenhouse

The oceans absorb almost a third of the carbon dioxide that humans pump into the atmosphere. This would imply that the amount of carbon dissolved in the sea should rise in tandem with the increasing amount of this greenhouse gas in the air. However, this is not the case. The Southern Ocean, for one, has been exhibiting a saturation effect over the last 25 years. This effect has been measured for the first time by an international team of researchers working under the leadership of the Max Planck Institute for Biogeochemistry in Jena. Although carbon dioxide emissions have risen by 40 percent since the early 1980s, the Southern Ocean has not absorbed more carbon dioxide. The blame lies with a feedback effect: climate change, which is caused at least in part by greenhouse gases, is affecting the carbon cycle of the oceans. (SCIENCE, May 17, 2007)

Geochemists call forest fires, smoking chimneys and also some regions of the world's seas carbon sources. However, if a forest or an ocean absorbs more carbon dioxide than it gives off, they refer to a carbon sink. The more carbon dioxide the atmosphere contains, the more it should push into the sea. This was how the Southern Ocean changed from being a source to becoming a sink. Just a few decades ago, it was releasing carbon dioxide; now it has become a net absorber of carbon dioxide, since the concentration in the atmosphere has grown so drastically. This is a chemical balance issue and can, in principle, also be observed in a soda maker.

If the Southern Ocean were to continue to uphold this principle, it could lessen the growing change in the climate. "However, climate change is making the seas absorb less carbon dioxide," says Professor Martin Heimann, Director at the Max Planck Institute for Biogeochemistry in Jena. "This means that more anthropogenic carbon dioxide will remain in the atmosphere, which in turn will fuel climate change."

The international team of scientists, which includes researchers from the University of East Anglia and the British Antarctic Survey, now has analyzed observations to confirm this positive feedback effect. Prior to this, it was predicted on theoretical grounds only. The scientists from the Max Planck Institute in Jena have evaluated observations from 42 stations located throughout

the world. The stations record the concentrations of greenhouse gases in their surroundings, and some of them have been doing so since the early 1980s. The intensity of the increase or decrease in concentration between the individual stations depends, among other things, on the flow of air, as well as on how much gas the sinks extract from the air. Working backwards from their measure-

The stations (stars) where scientists have measured carbon dioxide concentrations in the air are distributed throughout the globe. This has allowed them to determine how much greenhouse gas the Southern Ocean is absorbing.

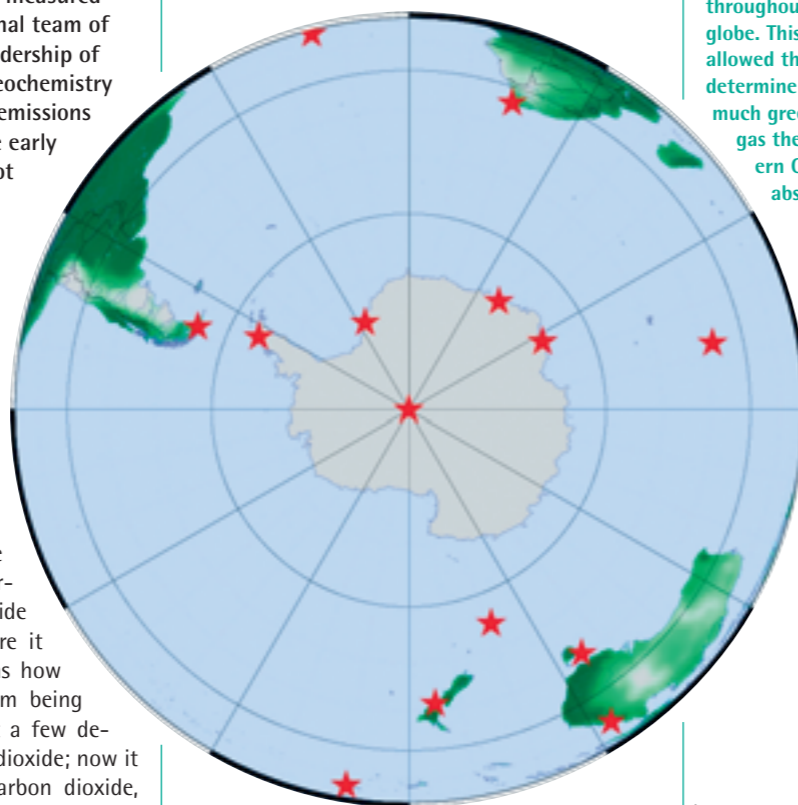


ILLUSTRATION: MPI FOR BIOGEOCHEMISTRY

ments, the scientists were able to calculate how much carbon dioxide the Southern Ocean is absorbing, and how much its capacity has changed over the last 25 years.

The Southern Ocean should actually be absorbing more greenhouse gas today than when the observations began; after all, the concentration of carbon dioxide in the atmosphere has increased significantly. Instead, absorption has stagnated during the last 25 years, as revealed by the observations analyzed by the team of scientists. The blame lies with climate change, which fans the winds over the Southern Ocean. These, in turn, alter the ocean currents, bringing to the surface water that is already saturated with carbon dioxide. Similar phenomena can be observed in other locations. "We have to assume that feedback mechanisms of this kind are increasing climate change in other parts of the world, as well," says Heimann.

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Panorama

A NEW TYPE OF FLEA was discovered by researchers from the Max Planck Institute for Ornithology in Radolfzell on the nestlings of the lesser burrowing parakeet, which breeds on the steep cliffs of Patagonia. It is a sand flea of the *Hectopsylla* genus that attracted the scientists' attention with its unusual, and thus far unique, nesting place, infesting the chicks' nostrils and the area under their tongues. *Hectopsylla narium*, the name of the newly discovered flea, is related to *Tunda penetrans*, which carries tungiasis, a tropical disease. The females of this species like to burrow in the skin of human feet, where they lay their eggs and cause serious infections. The other 22 sand flea species are found mainly in South America on various mammals and birds.



Researchers at the Max Planck Institute for Ornithology discovered a new type of flea: *Hectopsylla narium* (this electron microscope image shows its head), which lives in the nostrils and under the tongue of lesser burrowing parakeet chicks.

THE CULTIVATION OF FUEL PLANTS that create larger quantities of biomass has been the object of study by scientists at the Max Planck Institute for Plant Physiology and the University of Potsdam. They are investigating whether and how the plants can be made to increase their production of biomass – an organic substance that can function as the carrier and supplier of regenerative energy. In order to create such bulked-up plants, their metabolism must be researched in detail: which of their constituents (sugar, acids and proteins) and which external factors (light, water and nutrients) affect growth and therefore the production of biomass? As a model organism for investigating these issues, the researchers are using a broad range of genetically well-characterized lines of mouse-ear cress, *Arabidopsis thaliana*, which is distinguished by wide variations in its growth rate. These differences must be related to the constituents of the individual plants in order to determine the prognosis for their yields.

MOUNT ETNA SUPPLIES CATALYSTS that are suitable for the large-scale manufacture of nanotubes and nanofibers from carbon. This was revealed by researchers at the Max Planck Society's Fritz Haber Institute in Berlin. In a first step, they pulverized lava rocks from Etna and heated them to 700 degrees Celsius in a hydrogen atmosphere, reducing the finely distributed iron oxides in the lava to elemental iron. Then they passed a mixture of hydrogen and ethylene gas over this powder – and obtained tiny carbon tubes and fibers that collected on the lava particles. This process could facilitate the efficient and low-cost manufacture of carbon nanotubes. After all, this volcanic catalyst from

Etna is available in large quantities, and the iron, which is the actual catalyst, is finely distributed on and bound to the extremely porous lava, which thus acts as both catalyst and carrier. And yet another advantage: the process requires no wet chemical steps.

TO EXAMINE THE BRAIN DURING REM SLEEP, scientists at the Max Planck Institute for Psychiatry have, for the first time, used a combination of measuring methods: Parallel to registering brain waves with electroencephalography (EEG), they used an fMRI scanner to record brain activity in sleeping and dreaming subjects. In this way, they were able, for example, to precisely track the brain's reaction to acoustic stimuli, such as piano music, during sleep. Measurements taken during REM sleep – so while the subjects were dreaming – provided particularly interesting findings: repeated short phases of high brain activity were detected in which the brain shuts out external stimuli and the sleeper is practically helpless. However, these were interspersed with phases in which the external stimuli were perceived at a rudimentary level, and occasionally even incorporated into the dreams.



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 Further information is available at www.maxplanck.de