04 | 2022

MAX PLANCK *Research*

JURISPRUDENCE
Emojis in Court

CHEMISTRY
Greenhouse Gases Electrified

PHYSICS
Focal Points in Nuclear Fusion

CONNECTION TO THE WORLD

PHOTO: ADOBE STOCK / CHEPKO DANIL

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Our senses are our connection to the world. It is through them that the brain receives vital information about our environment. Children practice using them through play and in doing so gain essential experience for life.

EDITORIAL

Dear Reader,

According to Aristotle, man has five senses. Others talk about six or seven, while according to Rudolf Steiner and his anthroposophical theory of the senses, we possess as many as twelve. How many senses we have is, therefore, also a matter of taste.

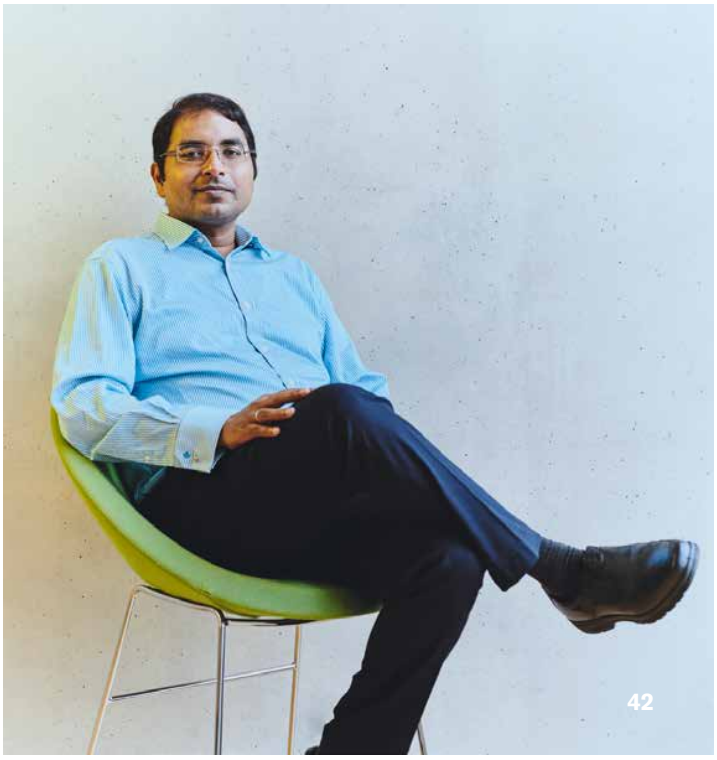
The importance of our senses in our lives becomes apparent when we lose one. People with hearing disorders, for example, find it difficult to make contact with other people. But a new technology is set to make hearing easier for those who cannot benefit from hearing aids. A crucial element in this process is a light-sensitive protein that originates from algae.

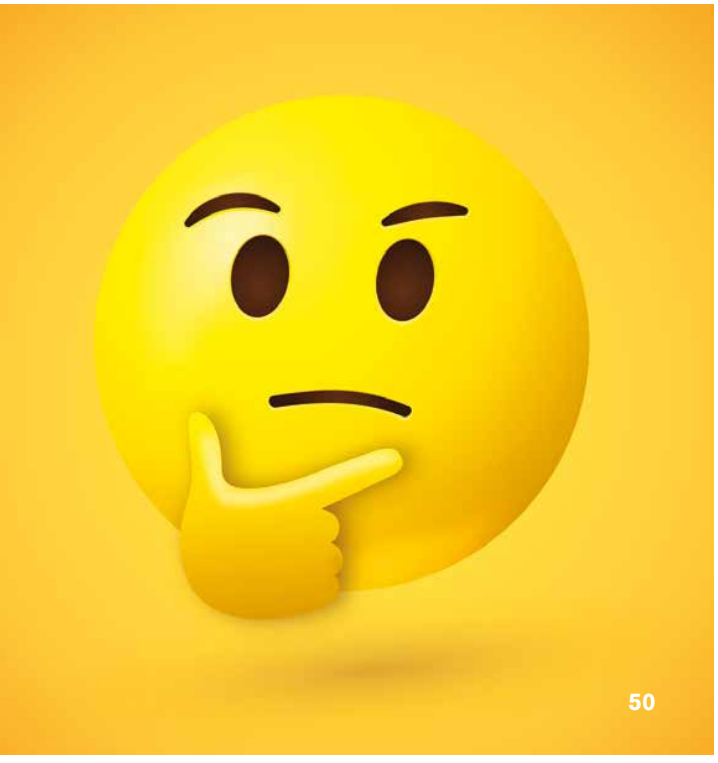
Hearing is one thing, but how we perceive what we hear is another. That applies particularly to music: culture and listening habits determine how we perceive rhythms. Be they indigenous peoples in the Amazon, people in Korea, or in the United States – every cultural group has its own musical world in mind. One popular children's game helps scientists investigate the different perceptions of rhythms.

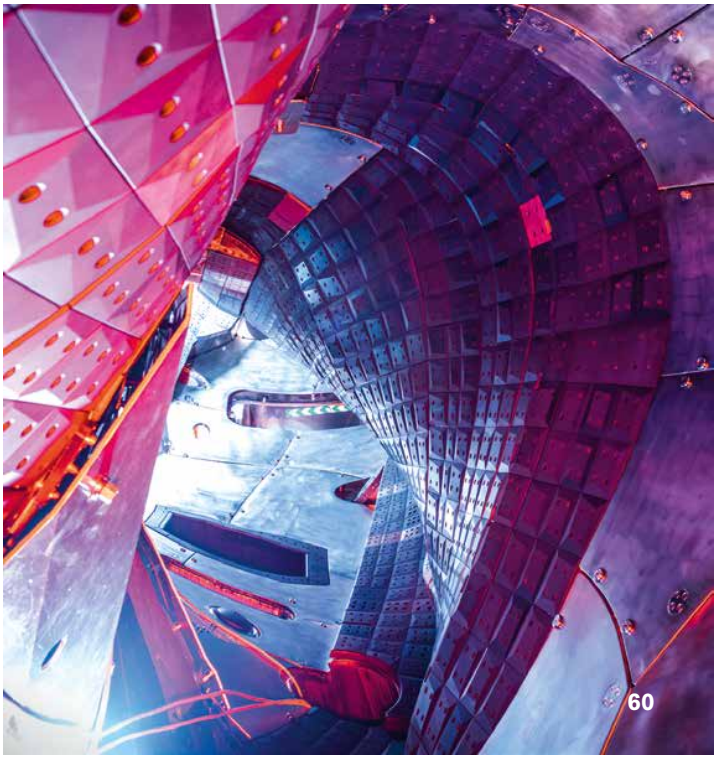
Other senses, meanwhile, are somewhat alien to us. The sense of magnetic fields, for example. Birds have it, along with amphibians, fish, and bats. And mole rats. These rodents with their monstrous incisors perceive the earth's magnetic field and can navigate their underground colonies in this way. In a labyrinth, the animals demonstrate their orientation skills for science.

We hope you enjoy this issue!

Your editorial team







IMAGES: SCIENCE PHOTO LIBRARY / FURNESS, DR. DAVID (TOP LEFT); ANNA ZIEGLER FOR MPG (TOP RIGHT); ADOBESTOCK / VILMOS (BOTTOM LEFT); JAN HOSAN / MPI FOR PLASMA PHYSICS (BOTTOM RIGHT)

30 | *SENSITIZED*

The sensory cells of the cochlea transmit sound signals to the auditory nerve.

42 | *ENGAGED*

Krishna Gummadi wants to make algorithms more fair and transparent.

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Courts will have to decide what emojis express in online communications.

60 | *ISOLATED*

Plasma should ideally never come into contact with the wall of a fusion chamber.

CONTENT

ASTEROID RYUGU

Its shape resembles that of a diamond, and it is indeed something of a scientific treasure: Ryugu, an asteroid roughly one kilometer in size that rounds the sun once every 475 days, passing through Earth's orbit in the process. But don't worry, the cosmic rock doesn't pose any danger to us. It has been the subject of research for some years now – and has already received visitors. These include the Japanese space agency, who sent the Hayabusa 2 probe to the celestial body in 2014. After taking soil samples, the scout flew back and dropped off its "message-in-a-bottle" containing the precious cargo near the Australian town of Woomera in December 2020.

Five grams from the "Dragon Palace," which is what "Ryugu" means in Japanese, ended up in labs on earth and were subjected to a thorough analysis in accordance with all standards of measurement. The material exhibits a loose, granular structure and shows obvious signs of prolonged reaction with water. Amino acids and other complex organic molecules were also found.

But where did Ryugu come from? Although it travels quite close to the sun, it probably originates from further afield. This is, at least, what studies conducted by the University of Göttingen and the Max Planck Institute for Solar System Research show. According to them, the Dragon Palace was born at the furthest edge of the solar system. The parent bodies of carbon-rich asteroids – including Ryugu – were formed there more than 4.5 billion years ago. As the gas and ice giants JupIter, Saturn, Uranus, and Neptune got nearer, it was then flung on a chaotic voyage toward the sun.

The rotation of Ryugu
https://en.wikipedia.org/wiki/162173_Ryugu

ON LOCATION

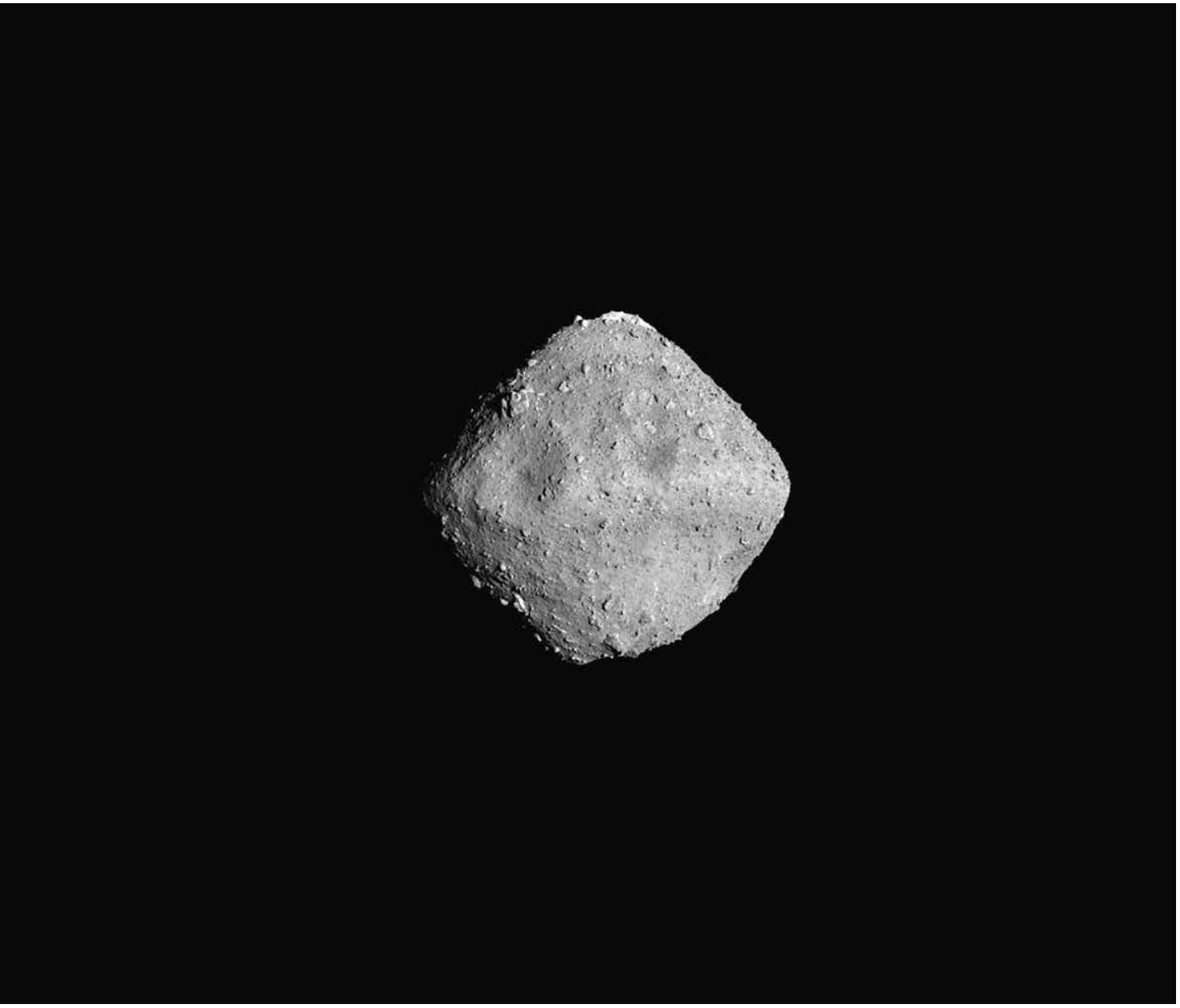

IMAGE: JAXA, UNIVERSITY OF TOKYO & COLLABORATORS

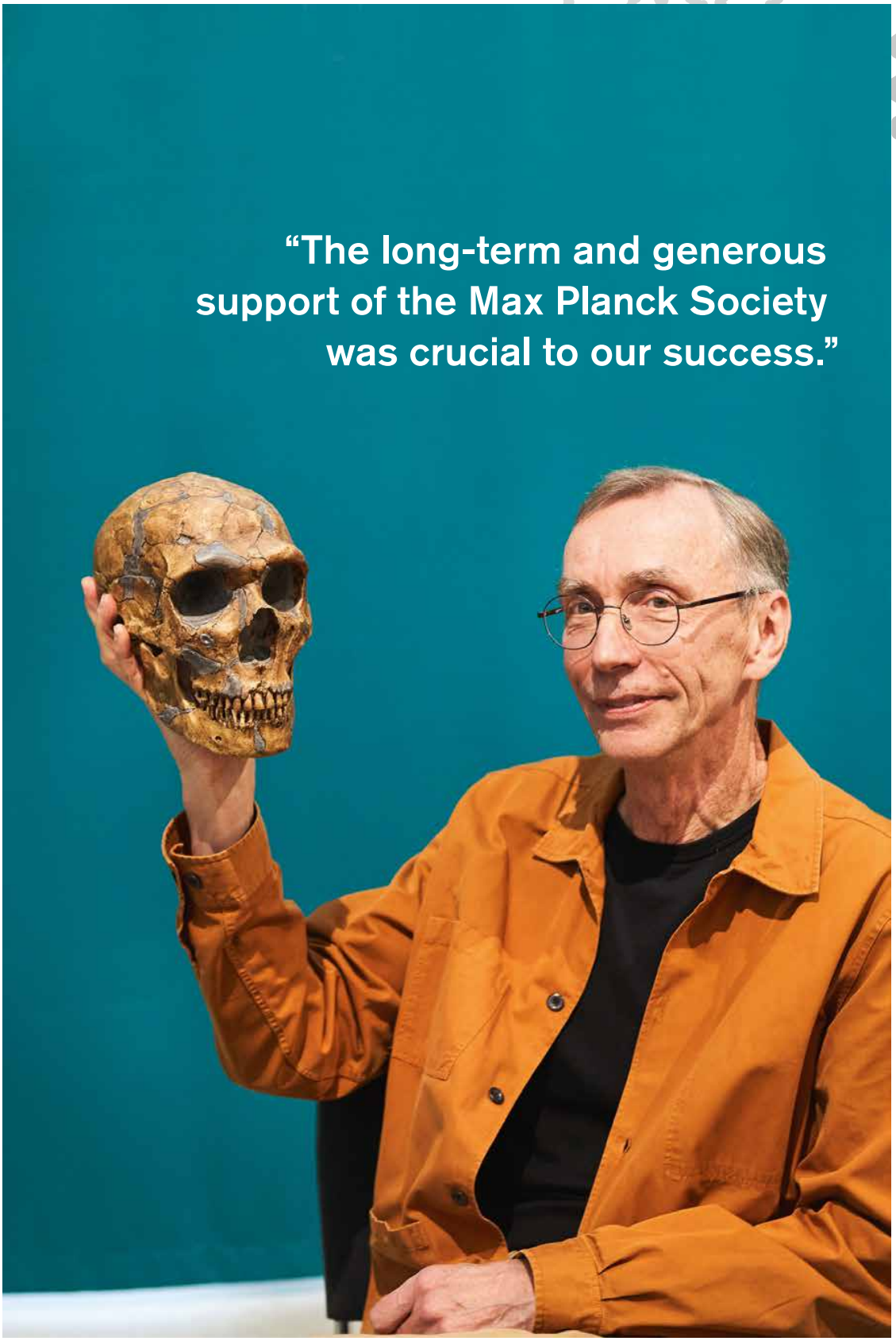

PHOTO: ANNA SCHROLL FOR MPG

2022 NOBEL PRIZE

SVANTE PÄÄBO

The circular DNA molecules in the mitochondria are a great deal smaller than the DNA in the cell nucleus and therefore, easier to analyze. After an organism dies, the genetic material breaks down into fragments of different lengths. However, most of the DNA comes from microorganisms.

Can DNA, the genetic material, survive in the bones of long-dead animals and humans and provide clues about their ancestry and relationships? That question has driven Svante Pääbo's research over the past forty years and has now landed him the Nobel Prize in Physiology or Medicine.

Isolating DNA from ancient bones is not easy, as the old DNA breaks down into small fragments, chemically modified and present in tiny amounts compared to the huge quantities of DNA from bacteria and fungi that colonized the bones when they were in the ground. Over many years, Pääbo's group has developed techniques to overcome these issues. This has created a new research field, paleogenomics, which centers on using museum or fossil material to gain direct insight into evolutionary relationships of animals, plants and pathogens.

Pääbo's own research at the Max Planck Institute for Evolutionary Anthropology in Leipzig has focused on extinct forms of humans. In 1997, he determined the first DNA sequences from a Neandertal by targeting its mitochondrial genome. The mitochondrial genome is present in many copies per cell, making it easier to sequence. The results showed Neandertals to be quite distinct from modern humans. The mitochondrial genome is a small piece of DNA passed only from mother to offspring, however; in order to get a complete view of the genetic history of Neandertals, it was necessary to study their entire genome.

In 2006, inspired by the development of new sequencing technologies, Pääbo initiated an ambitious collaborative project, supported by the Max Planck Foundation, to sequence the Neandertal genome. This culminated in the presentation of a draft version of the Neandertal genome in 2010. The data revealed that Neandertals mixed with modern humans. As a consequence, present-day people whose genetic roots are outside Africa carry about two percent Neandertal DNA. As different people often carry different Neandertal DNA fragments, at least half of the Neandertal genome still exists in people today.

In the course of sequencing DNA from ancient human remains, Pääbo's research group discovered a previously unknown form of humans, which they named Denisovans – after the cave in southern Siberia where the small bone from which they determined the DNA sequence was found. They showed that Denisovans were distant relatives of the Neandertals, and have themselves contributed DNA to people who today live in Asia.

Svante Pääbo's and his team's work now seeks to understand the key differences distinguishing present day humans from Neandertals and Denisovans, as well as understanding the consequences in people today of genetic variants originating from Neandertals and Denisovans. For example, some Neandertal variants increase our sensitivity to pain, others decrease the risk of miscarriage during pregnancy, while yet others increase the risk of becoming severely ill when infected by Sars-CoV-2.

←

ILLUSTRATION: HENNING BRÜER; IMAGE: PICTURE ALLIANCE/SZ PHOTO

MOMENTUM FOR INDUSTRY

A spin-off from the Max Planck Institute of Molecular Plant Physiology recently added some momentum to Bayer's crop protection research. The German biotech startup Targenomix, which uses innovative methods from systems biology and computational life sciences, will add momentum to the chemical and pharmaceutical company in its search for new mechanisms of action for crop protection products. With the acquisition, Bayer aims to accelerate the discovery and development of molecules that have the potential to make agricultural production more sustainable, despite challenges such as climate change, and to increase weed, disease, and insect resistance in crops.

www.mpg.de/19478039

PHOTO: SHAIITH/ADOBE STOCK

From research to application: biotech start-up Targenomix is set to expand Bayer's capabilities in the area of crop protection.

CENTER FOR GREEN CHEMISTRY

A concept developed by Max Planck scientists has prevailed in a competition to establish research centers in former coal-mining regions. The Federal Ministry of Education and Research, the Free State of Saxony, and the State of Saxony-Anhalt selected the concept of the Center for the Transformation of Chemistry (CTC), among others, from nearly one hundred proposals. The aim of the new center is to transform the chemical industry into a sustainable circular economy by developing sustainable production processes based on renewable natural resources and recycled materials. The idea for this came from Peter H. Seeberger and Matthew Plutschack at the Max Planck Institute of Colloids and Interfaces. The CTC will receive institutional funding of up to 170 million euros per annum.

www.mpikg.mpg.de/6750322

PHOTO: HDR GERMANY

New research site: the visualization shows the Center for the Transformation of Chemistry on the land of the former sugar factory in Delitzsch near Leipzig.

OUTSTANDING ✶

SARAH O'CONNOR

PHOTO: SEBASTIAN REUTER

Sarah Ellen O'Connor, Director at the Max Planck Institute for Chemical Ecology, has been awarded the Leibniz Prize of the German Research Foundation for her fundamental discoveries in plant biosynthesis. The chemist researches biosynthetic pathways in plants with the aim of deciphering the synthesis of complex natural products such as cancer-inhibiting or neuroactive substances.

IN BRIEF

PHOTO: JÉRÉMIE BOISSIER / IRAM

An ear into space: the NOEMA observatory uses its antennas to scan the universe in the radio range.

BROADENED HORIZONS

The NOEMA radio telescope on the Plateau de Bure in the French Alps is now equipped with twelve antennas, making it the most powerful radio telescope of its kind in the northern hemisphere. Eight years after the inauguration of the first NOEMA antenna, this large-scale European project is now complete. Thanks to its twelve antennas, which can be moved back and forth on a special rail system of up to 1.7 kilometers in length, NOEMA is a unique instrument for astronomical research. During observations, the twelve antennas act like a single telescope. The NOEMA's maximum spatial resolution is so high that the observatory would be able to detect a cell phone from more than 500 kilometers away. The telescope is operated by the international institute IRAM, in which the Max Planck Society holds a stake.

www.mpg.de/19315974

FOR FREEDOM IN IRAN

The Max Planck Society declares its solidarity with the students and scientists in Iran in their desire for greater freedom. It condemns the brutal actions of the security forces and demands the immediate release of all those arrested in the course of the protests. Civil liberties are precious. Freedom of expression, freedom of the press, and academic freedom are also prerequisites for successful international scientific cooperation. The Max Planck Society would like to maintain the relationships with its Iranian scientific partners that have been built up over decades and continue to collaborate with them even under these very difficult conditions.

www.mpg.de/19437723

GENETICS OF DYSLEXIA

It is known that dyslexia occurs more frequently in some families – partly due to genetic factors – but until now, little was known about the genes involved. An international research team, including members of the Max Planck Institute for Psycholinguistics in Nijmegen, has now identified 42 genes that are clearly linked to dyslexia. About one-third of the genetic variants have previously been associated with general cognitive abilities and educational success.

www.mpg.de/19385189

PROPULSION OF SOLAR WIND

Our sun constantly blows a stream of charged particles of varying speed into space, and a particularly strong solar wind can produce auroras or disrupt satellite communications. The fast solar winds with speeds of more than 500 kilometers per second originate from the interior of coronal holes, which are regions that appear dark in the ultraviolet radiation of the solar outer gas atmosphere (corona). The origin of slow solar winds, which also blow at supersonic speeds of 300 to 500 kilometers per second, has been less clear so far. But now, with the help of the U.S. satellite GOES, a team led by the Max Planck Institute for Solar System Research has visualized a dynamic network of elongated, interwoven plasma structures in the central solar corona. The ultraviolet telescope looked into a region that had not been explored before. In combination with the measurement data of other space probes as well as computer simulations, a clear picture emerges: the hot solar plasma flows in the middle corona along the open magnetic field lines of the coronal network. Where the field lines cross and interact with each other, energy is released – and this accelerates the particles of the slow solar winds.

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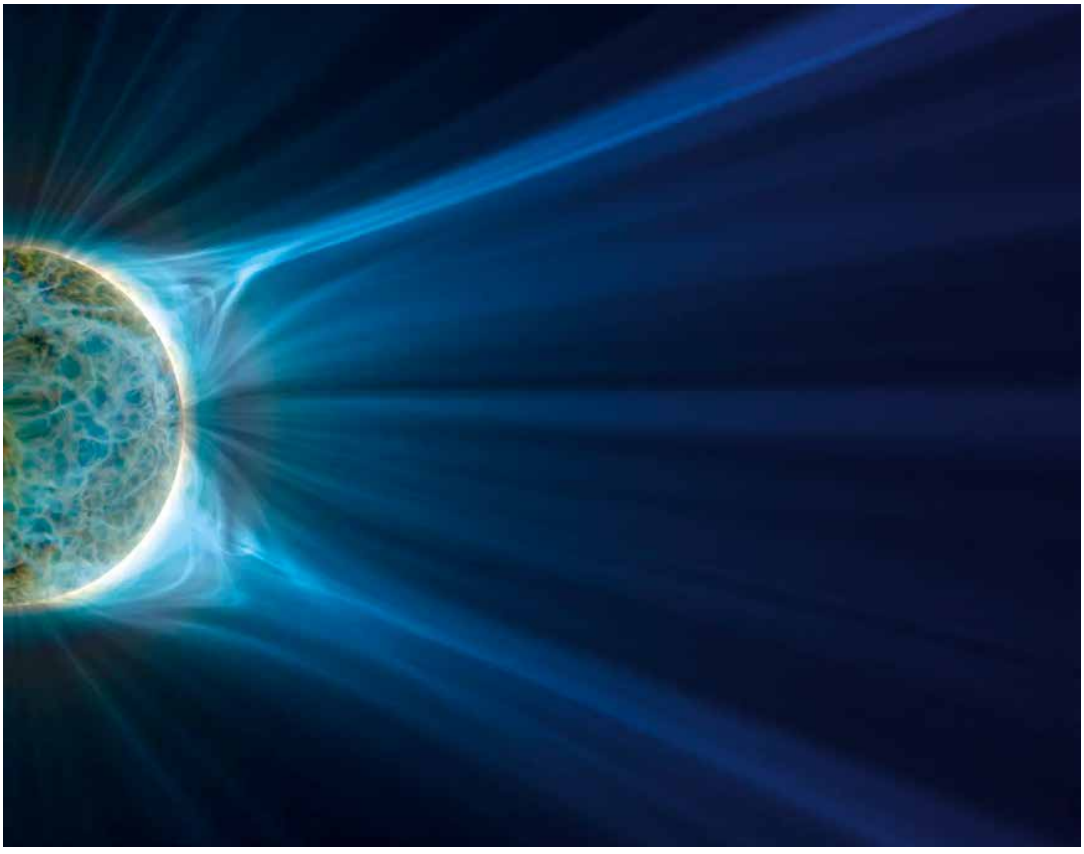

The atmosphere of the sun: ray-like structures in this snapshot from a computer simulation show the architecture of the observed coronal network.

IMAGE: NATURE ASTRONOMY, CHITTA ET AL.

ENERGY BOOST FOR BATTERIES

An invention by researchers at the Max Planck Institute for Medical Research could make batteries much lighter, more efficient, and safer in future. The team has found a way to create very fine metal fleeces that could serve as current collectors in the electrodes of rechargeable batteries and replace the aluminum and copper foils used so far. The metal fleeces make it possible to increase the thickness of battery cells to ten times that of cells commonly used today, thus saving material and weight. Since the metal fleeces have a much larger surface area than conventional current collectors, batteries with these kinds of current collectors can be charged and discharged much faster. What's more, the metal mesh reduces the electrical resistance of the electrodes and increases their mechanical stability, making the batteries safer. Batene GmbH, a spin-off of the Institute, has licensed the invention and is now marketing it, having received ten million euros in start-up funding from investors.

www.mpg.de/19463528/1107

PHOTO: HANNAH ROWLAND

The peacock butterfly (*Aglais io*) has eyespots on each forewing and hindwing, which appear to be staring directly at onlookers.

BUTTERFLY WINGS WITH THE MONA LISA EFFECT

Some butterflies have striking markings on their wings, eye-like spots that are supposed to deter predators from attacking. Researchers at the Max Planck Institute for Chemical Ecology in Jena, Germany, studied the deterrent effect of the spots and observed the way newly hatched chicks attacked artificial moths with eyespots on their wings. The inner circles of the spots were oriented so that the mock eyes appeared to look forward, to the left, or to the right. The researchers found that the chicks were then more hesitant to attack their prey when they approached from the perceived line of sight of the eyespots. With moths that had concentric circular eyes, the chicks approached with great caution from all directions. The reason for this is apparently the so-called Mona Lisa effect – named after the portrait by Leonardo da Vinci, whose pupils are symmetrically positioned in the iris and thus seem to follow the observer everywhere. Similarly, the eyes on the butterfly's wings seem to stare at predators in all directions.

www.mpg.de/19378715/1018

Neanderthal father with his daughter.

IMAGE: TOM BJORKLUND

FAMILY FROM PREHISTORIC TIMES

Fifty-four thousand years ago, southern Siberia was home to a group of Neanderthals consisting of at least eight adults and five juveniles. The clan included a father with his daughter and a young boy along with his cousin, aunt, or grandmother. These early humans hunted ibex, horses, and bison in river valleys and gathered the material for their stone tools. Researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig came across this extended family when they analyzed the DNA of bones found in two caves in the Altai Mountains in Central Asia. The extremely low genetic diversity suggests that the clan consisted of only ten to twenty individuals who had little genetic exchange with other groups. The connecting links between different extended families were primarily women – they apparently moved from their natal group to another more frequently than men.

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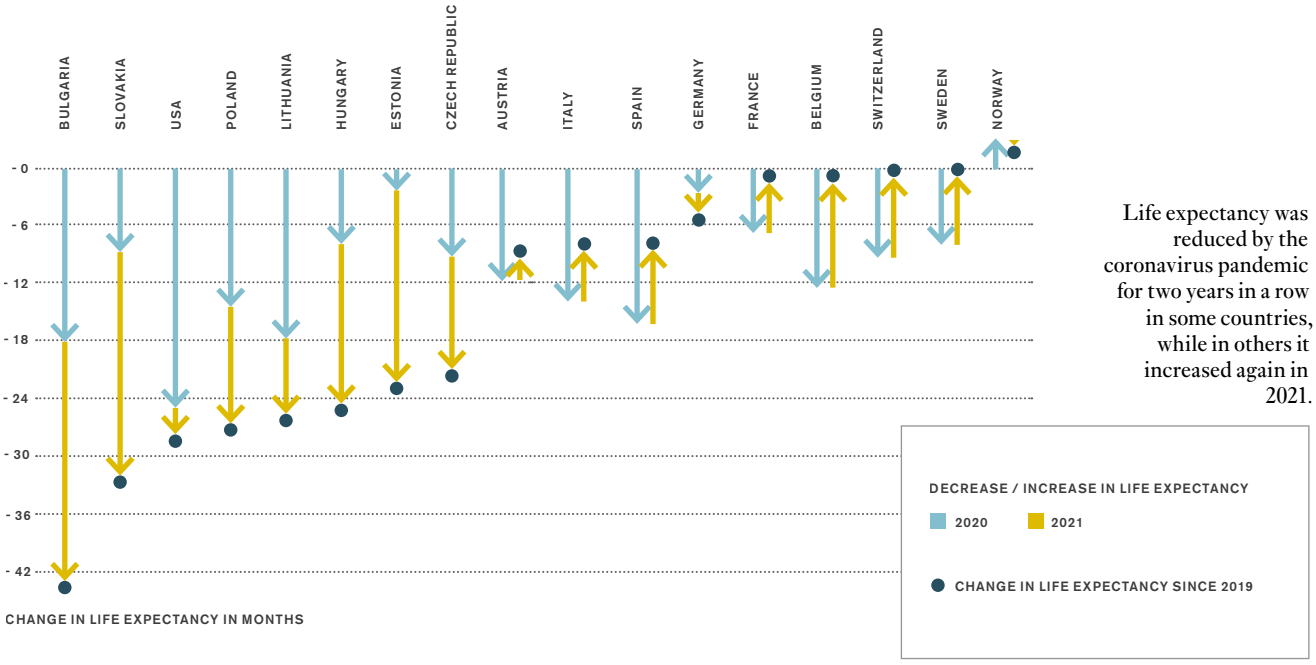

Life expectancy was reduced by the coronavirus pandemic for two years in a row in some countries, while in others it increased again in 2021.

GRAPHIC: GCO ACCORDING TO SCHÖLEY, J., ABURTO, J. M., KASHNITSKY, I. ET AL. LIFE EXPECTANCY CHANGES SINCE COVID-19. NAT HUM BEHAV (2022)

THE CORONAVIRUS SHORTENS LIFESPAN

Due to the coronavirus pandemic, period life expectancy fell in 2021 for the second year in a row in many Western countries. This is the result of a study conducted with the participation of the Max Planck Institute for Demographic Research in 27 European countries as well as the USA and Chile. Period life expectancy is a measure of the risk of death to which a population is exposed within a year. In Germany, the loss of period life expectancy was greater in 2021 than in 2020, at 3.1 months, but the overall decline for both pandemic years combined was comparatively moderate, at 5.7 months. In parts of Eastern Europe, meanwhile, the mortality crisis worsened considerably. In Bulgaria, for example, period life expectancy decreased by 2.1 years in 2021, which represents a drop of 3.6 years compared to the pre-pandemic level. More than a quarter of the loss was due to increased mortality among 40- to 60-year-olds. Bulgaria had the lowest vaccination rate of all the countries studied by the fall of 2021 and this, along with poorer health care and significantly more difficult living conditions, is likely to play a role there, as in other Eastern European countries. Only in France, Belgium, Sweden, and Switzerland did period life expectancy return to pre-pandemic levels in 2021. In Norway, it even increased slightly despite the pandemic.

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SAVING ENERGY BEGINS IN THE BRAIN

Winters aren't easy for the European mole: its metabolism – one of the fastest among mammals – constantly demands large quantities of food, more than is available during the cold winter months. Since it cannot hibernate or migrate, it solves this problem in an unusual way: it shrinks its brain. Researchers at the Max Planck Institute of Animal Behavior in Constance have discovered that the European mole shrinks its skull, and thus its brain, during the winter by eleven percent in the first year of its life, and then enlarges it again by four percent by summer. In the years that follow, the increase and decrease probably balance each other out. Iberian moles, on the other hand, do not change the size of their brains, even though they also find little food in the dry summer in their home country. The researchers conclude that not only scarce food but also cold weather drives brain size reduction. In addition to the European mole, shrews, stoats, and weasels can also shrink their brains in winter.

www.mpg.de/19235031/0919

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is the percentage by which the European mole's brain shrinks in its first winter.

CHIRPING FOR GOOD CHEER

A research team from the Max Planck Institute for Human Development and the University Medical Center Hamburg-Eppendorf has studied how traffic noise and birdsong affect the psyche. In an online experiment, nearly three hundred healthy test subjects were given either traffic noise or birdsong to listen to. Their mental health was recorded before and after the listening sessions. Even healthy people can have anxious thoughts or occasional paranoid perceptions. In the study, listening to traffic noise exacerbated depressive tendencies, while the sound of bird calls reduced anxiety and paranoia in participants. One possible explanation for these positive effects is that bird calls are subliminally associated with an intact natural environment, which diverts attention away from psychological stress and creates a feeling of safety and security. At the same time, however, birdsong seems to have little influence on manifest depressive states.

www.mpg.de/19373671/1017

PHOTO: AXEL GRIESCH

Chirping keeps you chirpy: listening to birdsong reduces anxiety and paranoid perceptions.

THE MYSTERY OF THE CLOSEST BLACK HOLE TO THE EARTH

There are an estimated hundred million black holes in our Milky Way Galaxy. So far, however, researchers have only directly observed the mass monster in the galactic center, while some other, much smaller ones have only been observed using indirect methods. Recently, the astrometry satellite Gaia achieved another success: it noticed tiny changes in the position of a star – as if an invisible companion object were tugging at it. This is evidently a double system, consisting of a visible, sun-like star and the invisible black hole with about ten solar masses. At a distance of 1560 light-years, it is the closest to Earth. The system, known as Gaia BH1, poses a number of puzzles for the team led by Kareem El-Badry of the Max Planck Institute for Astronomy. It is unclear, for example, how it could have formed at all. The progenitor star, which later mutated into a black hole, would have had a mass of at least twenty solar masses and a very short lifespan. It would have transformed into a supergiant before its lower-mass partner even had time to become a true star. How did the companion survive this episode? And shouldn't it have ended up in a much closer orbit than can be seen today? Now it's up to the theorists to explain the scenario.

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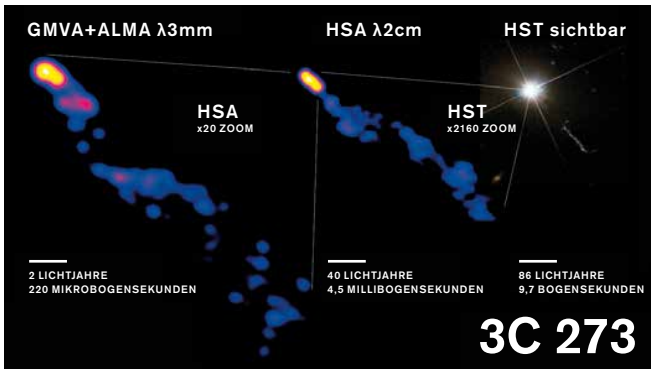


Zooming into the center: the left image shows the best view yet of the plasma jet of quasar 3C 273.

IMAGE: HIROKI OKINO AND KAZUNORI AKIYAMA; GMVA+ALMA AND HSA IMAGES: OKINO ET AL.; HST IMAGE: ESA/HUBBLE & NASA

QUASAR IN FOCUS

Quasars are the bright cores of galaxies, each containing a supermassive black hole. Most of these mass monsters emit so-called jets, high-energy streams in which matter shoots into space at nearly the speed of light. A group including researchers from the Max Planck Institute for Radio Astronomy have now taken a closer look at quasar 3C 273, which is about 1.9 billion light-years away from us. For their observations, the astronomers used a worldwide network of radio telescopes, which they combined with each other. This Very Long Baseline Interferometry (VLBI) provided images of the jet's point of origin near the black hole – where the hundreds of thousands of light-years-long plasma stream is focused into a narrow jet. A look inside the quasar's engine room shows that the plasma jet's aperture angle is slowly narrowing. The jet is narrowing even outside the region where the gravity of the black hole dominates. This behavior has also been observed in less active black holes. Now the researchers are tackling the question of why the bundling of the jets is so similar in different systems.

www.mpg.de/19564279

DRIVERS OF POPULISM AND POLARIZATION

Some consider digital media to be a threat to democracy, while others emphasize the opportunities for greater participation. Whether and how digital media really affect political behavior was the subject of a meta-study that also involved the Max Planck Institute for Human Development. The researchers found both positive and negative effects: on the one hand, online media foster the possibility of political participation and the mobilization of voters, which strengthens the democratic legitimacy of governments and parliaments. They can also impart political knowledge and ensure a more diverse news offering. On the other hand, communication among like-minded people in so-called echo chambers on social networks in particular can damage trust in politics and in democratic institutions. Trust in traditional media such as newspapers and TV stations is also declining. Furthermore, digital media promote populism and polarization among the population, although the effects differ from country to country: what is potentially destabilizing in established democracies can be beneficial for those that are emerging and can strengthen the opposition in authoritarian regimes. The positive impact of digital media is most pronounced in emerging democracies in South America, Africa, and Asia, while the negative effects can be seen most notably in Europe and the USA.

www.mpg.de/19475420/1108

MUSIC WITH LIMITED COVID RISK

Wind music has long been suspected of promoting infection with the coronavirus. Indeed, playing the clarinet can release relatively large numbers of pathogens such as Sars-CoV-2 – significantly more than playing the flute, for example. Otherwise, however, the risk of infection posed by an infected person playing a wind instrument is significantly lower than that of someone who is singing or speaking – given the same amount of time spent in their vicinity in each case. This is the conclusion of a comprehensive study conducted by the Max Planck Institute for Dynamics and Self-Organization in Göttingen and the University Medical Center Göttingen. The researchers determined the particle emission and the associated maximum risk of infection from the playing of twenty different wind instruments. According to the results, the particularly infectious larger respiratory droplets, above all, remain trapped in the wind instruments. Nevertheless, five to fifty times more aerosol enters the environment when a person plays a wind instrument than when they breathe. The results provide clues as to how concerts or rehearsals can be organized with the lowest possible risk of infection, even during the pandemic. ***www.mpg.de/19306683***

ESCAPING THE BANGS

Many humans look forward to the fireworks on New Year's Eve; birds, meanwhile, react to them with fear and flight.

PHOTO: HELMUT KRUCKENBERG

For two years, Germany was largely silent as the new year began. This year quite lIterally started with a bang as private New Year's Eve fireworks were once again allowed almost everywhere throughout the country. A study by the Max Planck Institute for Animal Behavior in Constance shows it is not only humans that suffer from the immense noise and pollution caused by fireworks. The researchers equipped more than 300 coots, barnacle geese, pink-footed geese, and bean geese in Germany, Denmark, and the Netherlands with GPS transmitters and recorded the birds' flight movements for eight years in the weeks before and after the turn of the year. The GPS data show that the wild geese leave their roosts more frequently than usual on New Year's nights, sometimes flying up to 500 kilometers. This flight takes its toll: to regain their strength, the geese have to rest for several weeks longer and eat more. For birds that do not manage to replenish their energy reserves, the fireworks can, therefore, prove fatal.

www.mpg.de/19528005/1127

Fruit flies can move the retinas in their eyes with the help of two muscles. This enables them to better estimate distances.

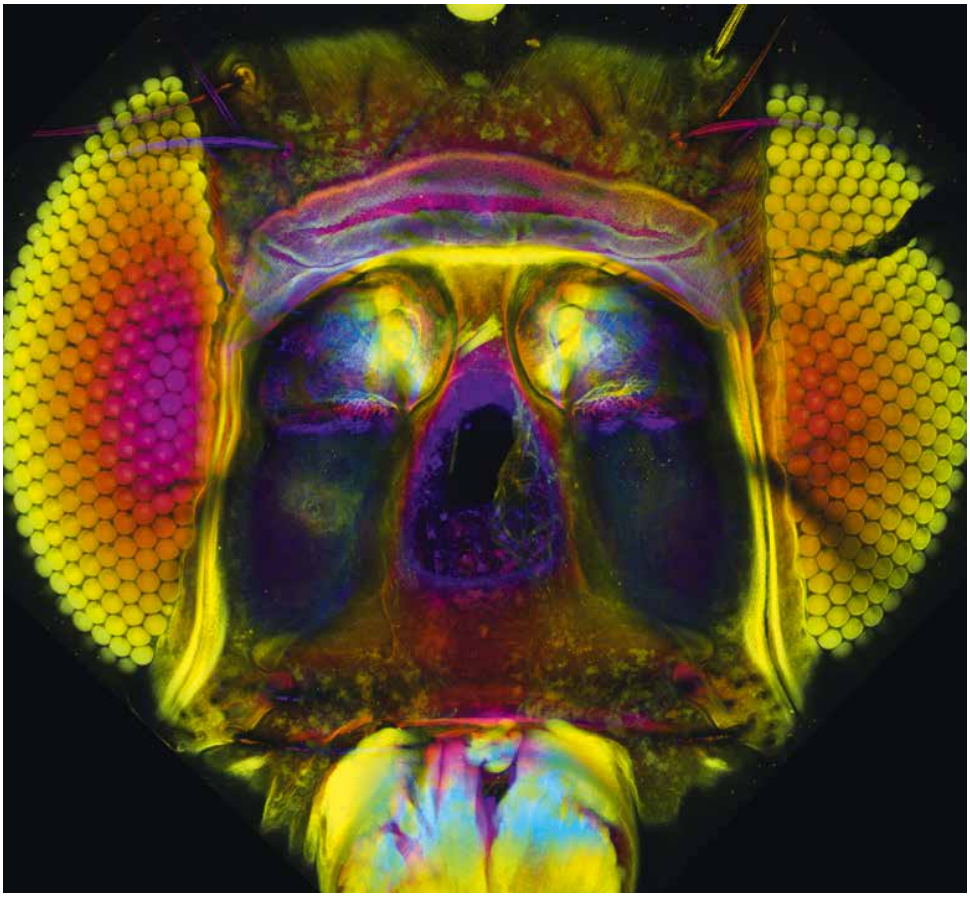


PHOTO: MAX PLANCK INSTITUTE FOR BIOLOGICAL INTELLIGENCE, IN FOUNDATION/ANJA FRIEDRICH

EYE MOVEMENT

The eyes of insects and other arthropods are firmly attached to their heads. Researchers at the Max Planck Institute for Biological Intelligence have discovered that, despite their fixed eyes, fruit flies can follow movements without having to turn their heads or bodies. They merely shift the retinas containing the visual sensory cells, thereby changing the image section that is displayed on the retina. The researchers also found that flies with less mobile retinas are less able to estimate the width of crevices in the substrate. The movements of the retinas, therefore, also seem to be important for spatial vision.

www.mpg.de/mpr-2022-041

INFLATION: WHY WAGES MATTER

Everything is getting more expensive. Prices for energy, food, and many other things are rising sharply. The European Central Bank has been trying to counteract this trend since June 2022: it has already increased interest rates four times and has announced further base rate hikes. But is this the right strategy? Political scientist Martin Höpner warns against overzealous monetary policy and recommends keeping an eye on wage trends.

Inflation appeared to have vanished. It was deflationary rather than inflationary pressure that plagued developed economies over the last two decades. There was little to indicate that that would soon change. Within just a year and a half we have landed in a different world. The last time that there were double-digit increases in consumer prices in Germany was during the Korean War in 1951 – and even then, only in two out of the four quarters.

Until the middle of 2022, the European Central Bank (ECB) refrained from counteracting the increase in prices with interest rate hikes. Their inaction drew severe criticism from Germany in particular, as the inflation rate of five percent in the second half of 2021 was already considerably above the target of two percent. The Central Bankers admit that the ECB reacted quite late – but when it did, it did so vigorously. Since July 2022, it has increased the main refinancing interest rate – the key base rate – four times, and it is hinting at further interest rate hikes. Now, I believe, that there is a danger of the ECB doing too much as a result of overzealousness. To be more precise, it irritates me that the ECB is not taking wage policy into account in its decisions. Let me explain what I mean by that.

→

VIEW POINT

MARTIN HÖPNER

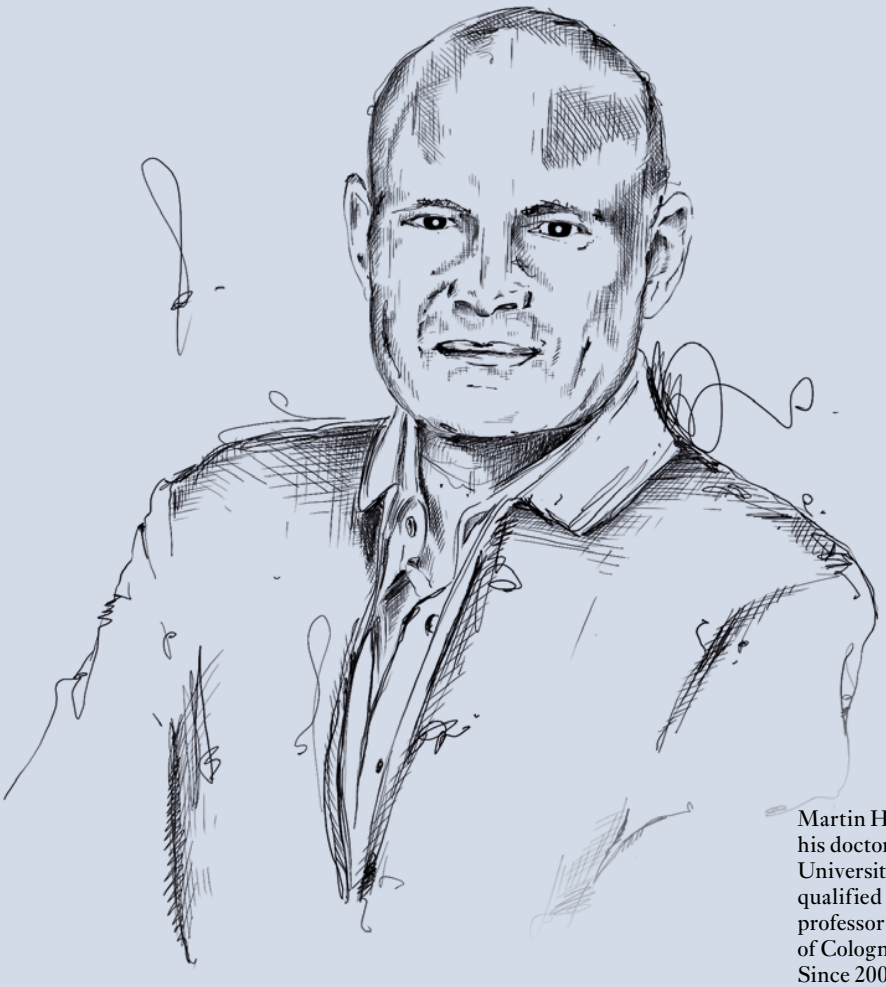


ILLUSTRATION: SOPHIE KETTERER FOR MPG

Martin Höpner completed his doctorate in 2002 at the University of Hagen. He qualified as a full university professor at the University of Cologne five years later. Since 2008, he has led an independent research group on the political economy of European integration at the Max Planck Institute for the Study of Societies in Cologne. Since 2012, he has also been a supernumerary professor at the University of Cologne. His research fields include the heterogeneity of the European economic and currency area, European single market freedoms, and the export-oriented German economic model.

To date, the causes of this inflation have predominantly been found on the supply side. During the pandemic, supply chain disruptions made primary products more expensive. There were also significant increases in energy prices, which fluctuated notoriously. While prices fell in 2020, they accelerated considerably in 2021. As we now know, that was only the beginning. Following the Russian attack on Ukraine and the resulting sanctions imposed on it, energy prices – particularly for natural gas – positively exploded. This has led to price increases across the board right up to the present time, as all products and virtually all services involve energy. Everything that money can buy is becoming more expensive.

Inflation with second-round effects, also referred to as wage-price spirals, is something different. This term is used to describe dynamics where prices and wages push one another up. Unions want to counteract the purchasing power losses suffered by their members and react to rising prices with rising wage demands, hard-fought industrial action, and ultimately high wage settlements. This further increases the cost pressure on firms, which are forced to increase prices in turn. This encourages unions to once again make high wage demands – and so on. Even if the initial causes of the price hikes are eliminated, inflation can be reinforced in this way. The fact that central banks have to stop such spirals through considerable interest rate increases is not in dispute.

UNIONS HAVE, TO DATE, REACTED TO THE PRICE INCREASES IN A VERY STABILITY-CONSCIOUS MANNER

The unions have, to date, reacted to the price increases in an extremely stability-conscious manner. Consider, for instance, the wage settlement reached in the German chemical sector in October 2022 or that in the metal industry in November. If you take into account the long terms of the wage agreements, the settlements were low (note also that the first wage increase in the metal industry was also preceded by an eight-month pay freeze). The unions are asking a lot of their members with wage agreements of this kind. There is no sign of wage-price spirals at present. I would go even further: the level of stability-focused wage policies that we are currently experiencing in Germany and also in other euro area countries to date is sensational. We didn't expect this. In my view, the ECB should take this into account and announce that it will increase interest rates further and quite significantly if second-round effects occur – but only then. Particularly in Germany, observers are currently encouraging the ECB to raise interest rates one way or another. They justify this by saying that it is necessary to reduce demand for goods and services. But this is the precise impact of a cautious wage policy anyway: the discrepancy between inflation and wage increases reduces real wages and hence demand.

Unfortunately, inflation will not disappear quickly even without second-round effects. This is evident from the gulf between the increase in producer prices, on the one hand, and consumer prices, on the other. Producer prices, which comprise manufacturing costs, including primary products, rose by not just ten percent or so in 2022 but by 30 to 40 percent. This means that there is still a lot of dormant cost pressure in firms, which will gradually be passed on to consumers. As a result, consumer prices are likely to continue to increase even when producer prices begin to fall again. Interest rate hikes would do nothing to change this. On the contrary, the increase in financing costs would add to the cost pressure that companies are facing.

If the ECB decides to increase interest rates in the medium term without taking wage responses into account, this may even increase the risk of second-round effects. Then there would be no disciplinary impact arising from the central bank's policy. Instead, the unions would be forced to conclude that how they respond to price rises obviously makes no difference to the level of base rates. But that's not all. By raising interest rates, the central bank would lower the refinancing capacity of states, which would then find it more difficult to ease the burden on poor households. Without state relief, however, unions would be left with no alternative but to provide relief by means of wage policy – but then with direct cost pressure impacts for businesses.

INFLATION REPRESENTS AN ENORMOUS ENDURANCE TEST FOR THE EURO AREA

How inflation develops in the medium term thus depends on wage policy. This is one of the reasons why we at the Max Planck Institute for the Study of Societies are devoting particular attention to wage policy. In the near future, a problem could arise from the fact that there is in truth not "one" wage policy in the euro area; instead, there are 19 different ones with different institutions, power relations, problem perceptions, and response patterns to economic shocks. The ECB can respond in an ordered fashion to uniform wage policy reactions – even if to the detriment of growth and employment – but not to 19 different ones.

To date, there have been few indications of wage-price spirals in other countries in the euro area either. But we don't know whether that will remain the case. If there is no accord with respect to wage policy responses, significant inflation spreads may emerge within the eurozone. This is precisely what happened during the first ten years of the euro, when the competitiveness of the countries with higher inflation rates deteriorated and their ability to refinance their national debt hit rock-bottom. This resulted in the euro crisis. Inflation thus represents an enormous endurance test for the euro area. The euro is not yet out of the woods.

SHIFTING SCRIPTS

Throughout history, people have created different writing systems that correspond to the peculiarities of each language. And these scripts have evolved in the process. How exactly can no longer be determined these days, as this evolution generally ended millennia ago. One exception, however, is the West African Vai script, which did not come into being until the 1830s. Its well-documented development provides researchers with insights into the evolution of scripts.

WRITING SYSTEMS

Different scripts around the world can roughly be divided into three systems – although there are also mixed systems.

Letter-based scripts are divided into alphabetic scripts, such as Greek, Latin, or Cyrillic, and consonant scripts, such as Arabic, in which vowels are not represented.

With syllabic scripts, the individual characters (graphemes) usually stand for several letters, for example, a combination of consonant and vowel.

In logographic scripts, each character has a meaning, but does not usually represent a whole concept. To represent concepts, characters are combined. In Chinese, there are often combinations of one or more symbols of meaning (pictograms) and a character that also includes pronunciation (phonogram).

Letter-based script

Arabic
كلمة
[kalima]
word, speech

Greek
λόγος
['lɔɣɔs]
word, reason

Syllabic script

Japanese (Hiragana)
こんにちは
[ko-n-ni-chi-ha]
hello

Vai
ꕉꔰꕲ
[ɓɛ-ɛ-na]
good

Logographic script

Chinese

日
[rì]
sun

青
[qīng]
blue-green

晴
[qíng]
in combination:
clear, bright

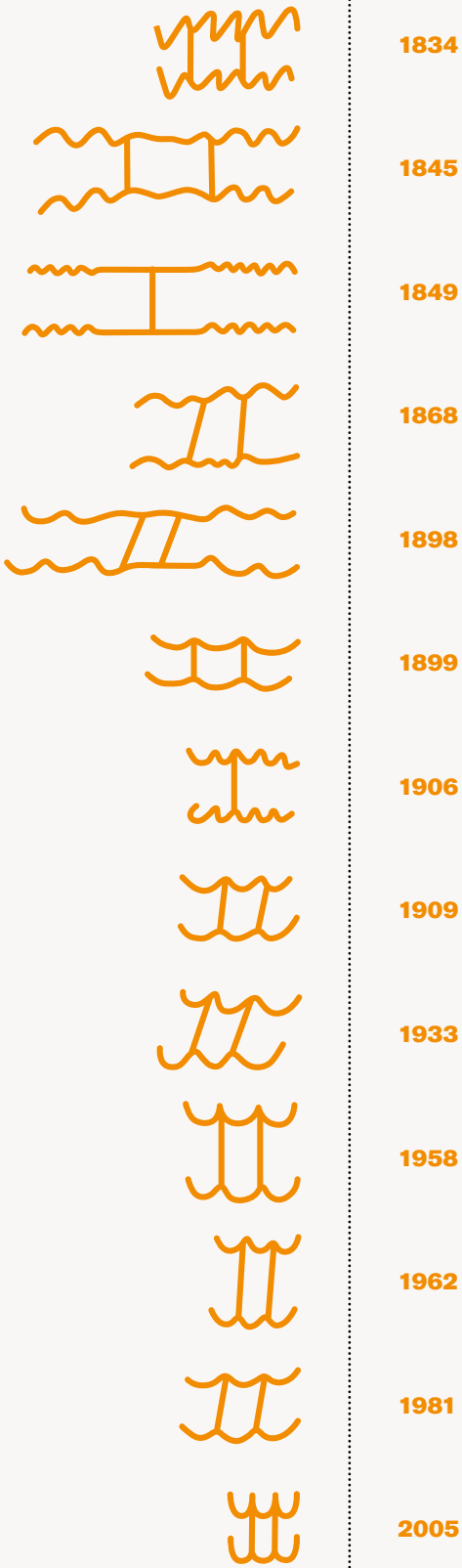
Mixture of pictogram (left) and phonogram (right)

DEVELOPMENT OF THE ALPHABET

Protosinaitic, the oldest known alphabetic script, can be traced back to hieroglyphics. The Phoenician script represents a further stage of development, from which, among other things, the Greek script developed. However, it is no longer possible to trace exactly which changes the individual letters underwent. Presumably, characters were simplified over time to make writing easier, but only to the extent that they can still be easily distinguished for reading.

Protosinaitic	Phoenician	Greek
from 1700 B.C.	from 1100 B.C.	from 800 B.C.
alp (ox)	ʔalf	alpha
maym (water)	mēm	my
kap (palm of the hand)	kaf	kappa

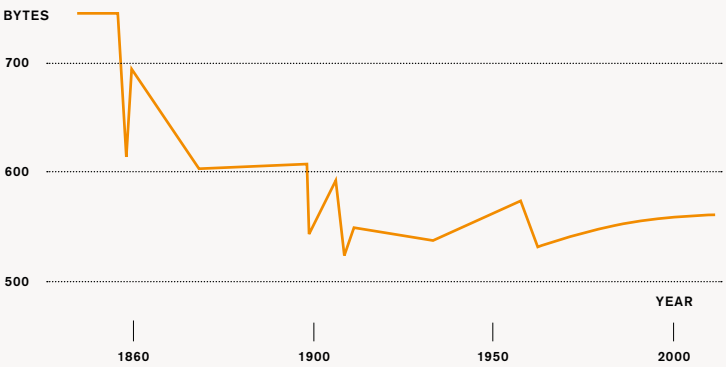
THE DEVELOPMENT OF THE CHARACTER <GA> IN THE VAI SCRIPT



THE VAI SCRIPT

This syllabic script with around 200 graphemes (script elements) was developed by illIterate people in Liberia from the 1830s onwards. Thanks to a large number of documents, the script's evolution from its beginnings to its standardization as Unicode in 2005 is well documented. An international research team, including Olivier Morin, Research Group Leader at the Max Planck Institute for Geoanthropology, has analyzed the changes in the characters with mathematical models. From this, it can be concluded that the individual character elements do indeed become simpler over time, as has long been suspected.

THE CHANGING COMPLEXITY OF THE CHARACTER <GA>



Descriptive complexity, as measured by the size of the image file in zip format, has decreased significantly over time.

FOCUS

CONNECTION TO THE WORLD

Musical diversity: Fidel Canchi Cuata from the indigenous Chimane people plays a kind of violin. Researcher Nori Jacoby's work in Bolivia included documenting regional musical instruments.

PHOTO: EDUARDO A. UNDURRAGA

SOUNDS DIFFERENT

TEXT: NORA LESSING

Drumming and singing, rhythm and sound – music moves us and brings us together. But what exactly we perceive when a song reaches our ears is something most of us wouldn't be able to articulate. For Israeli researcher Nori Jacoby, this simply won't do: at the Max Planck Institute for Empirical Aesthetics in Frankfurt am Main, he and his team are investigating, among other things, how people around the world perceive rhythms and pitches. In doing so, the researchers are gaining insights into much more than just the perception of music.

PHOTO: JOAQUÍN VALDÉS

Singing for research: the test subject from the Chimane people listens to intervals via headphones and sings what she hears. Cognitive researcher Nori Jacoby (right) controls recording and playback via laptop, with a local translator on hand to assist.

PHOTO: NORI JACOBY / MPI FOR EMPIRICAL AESTHETICS

The first time Nori Jacoby heard about the Tsimané who live in the Bolivian Amazon was in 2016, when he was a postdoctoral researcher in Josh McDermott's lab at the Massachusetts Institute of Technology (MIT). McDermott's lab studied how humans extract information from sounds. "Josh approached me," Nori Jacoby recalls, "and said, 'I'm going to the Amazon with cultural anthropologist Ricardo Godoy to work with the Tsimané. You're interested in music and you love to travel. Would you like to come with us?'"

Within a few weeks, the young scientist had traded the street noise and urban bustle of Boston for the humidity and shrill chirps of the Amazon rainforest. Here, in northeastern Bolivia, the Tsimané live in small communities where they hunt and fish, grow cassava and bananas. Most people here don't have cell phones or access to the Internet. "We did our experiments in small villages where the Tsimané live," Nori Jacoby explains. The experiments involved asking participants to tap out rhythms and to sing certain tones back to the experimenter. "The social aspects of the experiment were not that different from those you would encounter while running tests in New York or Boston," the scientist recalls. "But in terms of auditory perception, we soon realized that the experiences of the Tsimané are completely different from those of people brought up in the Western world."

Understanding what's going on in brain without words

A few years earlier, Nori Jacoby, who is a proficient player of several musical instruments and has worked as a

composer, had already had a similar experience. While on a concert tour in India, he worked closely with a local sound engineer. "This man's approach to sounds and music completely differed from mine – he treated sound in a way that I simply didn't understand." That experience, the researcher says, made a great impression on him – and the memory of it came up again as he worked with the Tsimané in the Amazon. "I asked myself: is it the same anywhere else? Do people all over the world hear the same sounds, but perceive them differently?" To find answers, the scientist conducted experiments in Mali and Uruguay, and began collaborating with researchers around the world. Since 2018, he has been leading a research group at the Max Planck Institute for Empirical Aesthetics in Frankfurt am Main. One of the group's goals is to systematically research the human perception of music and sounds across cultures.

Specifically, Nori Jacoby is concerned with the ways in which people experience musical elements such as rhythms, pitches, and intervals. His research studies how different brains represent such musical elements internally. "What I want to extract from people's minds with my experiments are the mental representations of the building blocks that make up music," the scientist explains. This is an interesting field of study since the musical world represented in the mind is by no means an exact copy of the musical world "out there": the mental representations a person has at their disposal, the things this person can perceive and produce, depend on previous experiences. Moreover, mental representations are not fixed, but change with each new auditory experience. This tricky situation for researchers is exacerbated by the fact that most people have no language to describe what they perceive when they listen. "So, the question I constantly ask myself is: without direct access to the brain, and preferably without words, how can I understand what is happening in a person's mind when they hear something? How can I read people's thoughts?"

Remote research site: the village of Emeya is located on the banks of the Maniqui River in the middle of the Bolivian rainforest. Those who wish to travel there must take a motorized canoe upriver for three days.

The answer the researcher has found is extremely creative: he makes use of humans' ability to imitate. "How do people around the world respond to music? They start singing along, stomp out the rhythm, move to it," says Jacoby. "No words are needed for this, just sound. So we asked subjects to listen to different sounds and imitate what they heard." In one experiment, the researcher played test subjects computer-generated rhythms, asking them to tap the rhythms back to him. What the test subjects didn't know was that they were actually playing a "telephone game" – with themselves. In the "telephone game" also known as "Chinese whispers," one person whispers a complicated word to another, who then whispers the same word as they have understood it, to a third person. Finally, the word, which progressively changes as the game goes on, is spoken aloud. In a similar way, subjects heard a rhythm that they were asked to tap out. A rhythm was then played to them again – an auditory, averaged copy of what they themselves had previously tapped. Over the course of several rounds, the test subjects tapped rhythms, which consistently underwent slight changes. What exactly did Jacoby and his team hope to find out in this way?

Expectation determines perception

"The interesting thing about the telephone game is that you start with an obscure word, but the game usually ends with a banal one," the scientist explains. "People regularly don't pass on the word they actually heard, but a word they think they heard. "With the help of experiments designed according to this scheme, researchers can thus learn something about people's listening expectations, or more precisely, find out which words are sufficiently familiar to test subjects that they expect to hear them – and which words this is less likely to apply to. It was precisely this mechanism that Jacoby and his team took advantage of to find out something about the subjects' expectations of rhythm.

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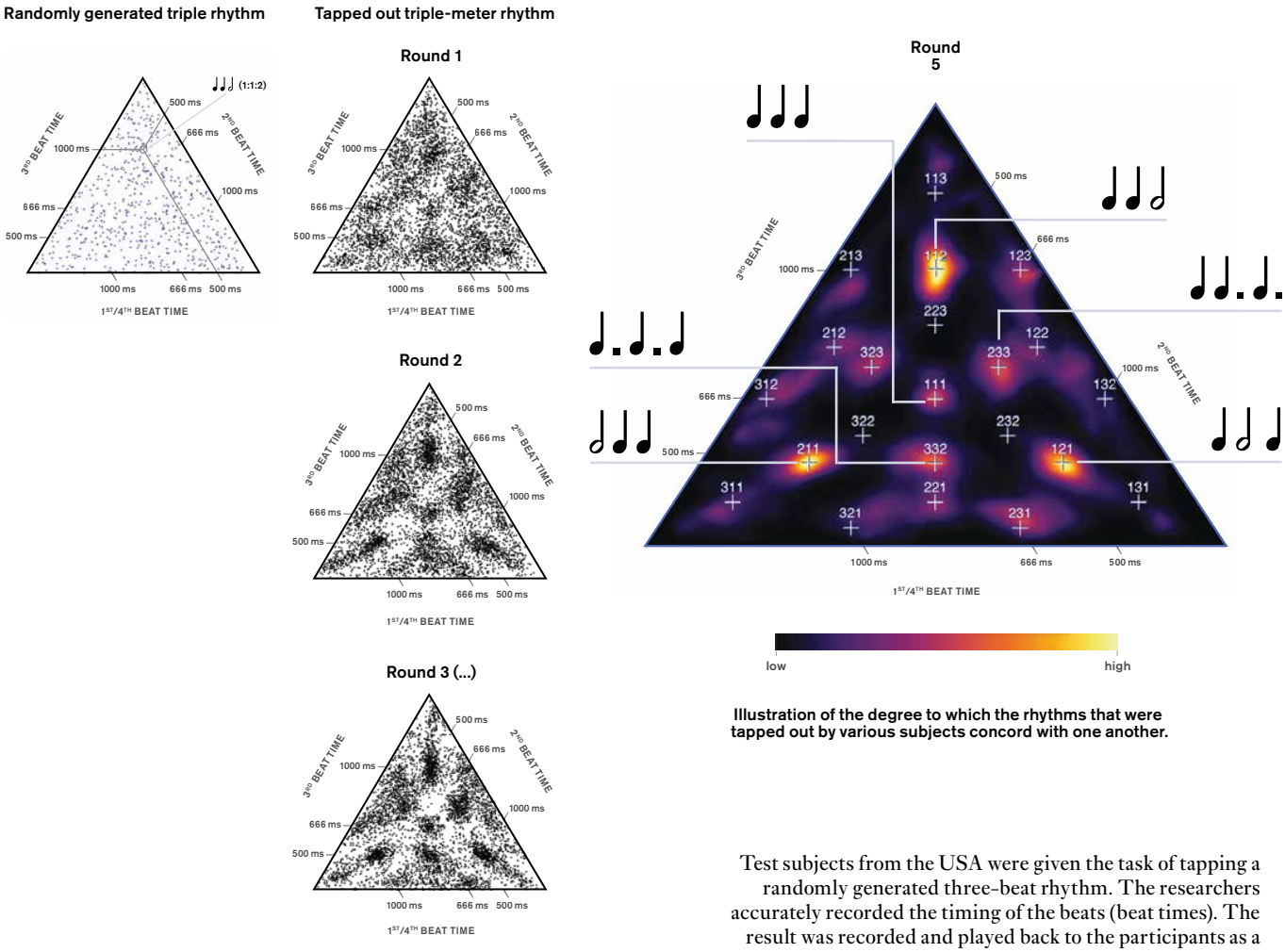


Illustration of the degree to which the rhythms that were tapped out by various subjects concord with one another.

Test subjects from the USA were given the task of tapping a randomly generated three-beat rhythm. The researchers accurately recorded the timing of the beats (beat times). The result was recorded and played back to the participants as a sample. Most of them fell into a familiar rhythm over the course of the five rounds, as shown by the clusters in the black-and-white graphs and the evaluation in the heat map.

They played them a computer-generated, "obscure" starting rhythm and received back "banal" target rhythms: equivalents of the participants' mental representations.

"It is actually like magic: we play a random, computer-generated rhythm, and without them having to explicitly tell us anything about it, what people imitatively tap gradually approaches their musical perceptual categories," Nori Jacoby enthuses. He and his colleagues have repeated the experiment countless times in 15 countries to date, including Korea, Uruguay, and the United States. Heat-map representations of the cumulative results demonstrate that people's tapping responses are highly ordered and follow distinct principles. "When we first saw the distributions, we were really astonished: the mental, musical representations of people with the same cultural background are the same. Many of the test subjects can't say anything about the rhythms they're tapping – and yet these rhythms sit in their heads, determine what they perceive when they hear something, and accordingly, what they tap out in the experiment."

It was not necessarily possible to infer the rhythms the participants would tap from their place of residence and native language. "A lot of our test subjects were students, for example, and although they came from countries as different as Korea and the USA and spoke very different languages, they often ended up tapping very similar rhythms in our experiment." The researchers are not exactly sure why this is the case, but they suspect that similar listening habits indicate similar experiences, meaning that students worldwide are exposed to the same influences and in many cases probably listen to similar music. In contrast to the stu-

GRAPHIC: JACOBY, J. H. MCDERMOTT, INTEGER RATIO PRIORS ON MUSICAL RHYTHM REVEALED CROSS-CULTURALLY BY ITERATED REPRODUCTION, CURRENT BIOLOGY, VOLUME 27, ISSUE 3, 2017, PAGES 359-370.

dents' fairly uniform results, the rhythms tapped by residents of big cities like Bamako in Mali or La Paz in Bolivia were enormously diverse. "Our analyses suggest that socioeconomic factors and the type of education a person has experienced, among other things, influence the rhythms they tap."

The study shows that whether in the Amazon, in Seoul, or in La Paz, people all over the world have a sense of rhythm. Which rhythms they actually perceive, however, varies. There are certain rhythmic structures which even Nori Jacoby, who has had extensive musical training, cannot pick out – the rhythm of the local dance Maraka, for example, which percussionists from Mali immediately recognize. The researcher reports this as just one of numerous examples his experiments have brought to light, revealing the great wealth of listening habits and musical traditions around the world. The fact that rhythms are heard so differently suggests that music perception is highly dependent on cultural imprints. At the same time, however, rhythms and other musical elements are often characterized by simple mathematical relationships. Does this not, in turn, suggest that music perception is universal on a more general level, expressing a kind of mathematical intuition?

Octaves don't sound the same to everyone

"Western thought is indeed deeply influenced by this idea, which can be traced back to Pythagoras," comments Jacoby, explaining how the ancient Greek philosopher found mathematical relationships to be fundamental to the world and thus to the perception of music. "Many physical phenomena, for example, string vibrations, are indeed associated with simple mathematical relationships like integer ratios. It has been widely assumed that the workings of the human mind also reflect Pythagoras' ideas." One prominent example of a physical phenomenon that links integer ratios with a sound that is often perceived to be harmonious is the octave. Many people in the Western world describe the interval as sounding the same, hearing the two notes as if the same note was struck twice, once with a lower and once with a higher sounding frequency. This is reflected in a notation system that uses the same letters – G and G', for example – for notes that lie an octave apart. Physically, the octave is characterized by the higher note vibrating exactly twice as fast as the lower one. Another phenomenon that seems to support Pythagorean ideas: with each note that is struck, the whole-number multiples of its frequency resonate, resulting in the overtone series. So, is the human perception of sound, with all its rhythmic and tonal diversity, ultimately determined by mathematical integer ratios? "If there really were a biological mechanism at work here, it would have manifested all over the world," comments Jacoby.

To test this hypothesis, the researcher designed another experiment based on imitation. He played Tsimané and participants from the United States two high-pitched tones outside their vocal range and asked them to imitate what they heard. "All participants mimicked the interval between the two tones very accurately," the researcher recalls. Yet in terms of the frequency of the notes as they were sung back, there were considerable differences: "When we do the experiment with musicians from the Western world, they sing the same notes to us three or four octaves lower – an expression of octave equivalence." Non-musicians from the US, however, did so only about half the time. In the Amazon, meanwhile, there was no sign of octave equivalence. "The Tsimané also sang the interval between the two notes very precisely. But the first note they sang did not relate to the source, and thus did not show octave equivalence," Jacoby explains. In a follow-up experiment, the researcher found out that the Tsimané also perceived the two tones an octave apart as blended. "However, this did not lead them to consider the two tones as equivalent. They judge the phenomenon differently than musicians from the Western world."

With his research, Nori Jacoby aims to get to the bottom of sound perception. But his results tell us about more than just our listening experience. Rather, human perception in general is under examination here, revealing itself empirically to be the product of an interpretative process that our brains undertake again and again on the basis of previous experiences and current sensory impressions. "What makes this even more exciting is that these processes happen simultaneously in all of us and are tremendously dynamic: on a larger scale, this is the basis of cultural development," Jacoby maintains. For people who place great emphasis on preserving tradition, this may not be the very best news. "Even if I think of myself as a traditional musician and play the same piece over and over again, my brain, and therefore, my perception of that piece, is constantly changing," says the cognitive researcher. For example, he explains, people perceived early bebop as very innovative at the time it emerged, and Elvis Presley's rock 'n' roll as scandalous. "These days, lots of people find both bebop and rock old-fashioned. This shows that our perception is forever in flux – and with it our culture."

www.mpg.de/podcasts/sinne (in German)

SUMMARY

Studies with people from many nations demonstrate that, contrary to popular belief, music is not a global language.

How a person perceives musical elements such as rhythms or intervals is shaped, among other things, by their culture and listening habits.

The way the brain processes music is influenced by each new experience and is constantly being altered by these experiences.

The coiled structure of the cochlea is revealed in an electron micrograph. Located within its coils are the auditory cells (orange – the membranes surrounding the cochlear canals are partially torn; this occurred during the preparation process for this photograph).

IMAGE: SCIENCE PHOTO LIBRARY / FURNESS, DR. DAVID

HEARING BY LIGHT

TEXT:
CATARINA PIETSCHMANN

Talking with friends, enjoying a concert, talking on the phone on noisy streets – people with hearing problems are often unable to hear things that others can. Tobias Moser aims to make sound accessible to those with hearing disabilities in a whole new way through a new generation of hearing protheses. Known as optical cochlear implants, these devices serve as an example of therapies developed on the basis of fundamental research.

Some 16 million people living in Germany suffer from a hearing impairment, and about 80,000 are deaf. Approximately two out of every one thousand children are born with a hearing impairment that until now has been irreversible; others develop a hearing impairment during the first few years of their life. Those born with little or no hearing have trouble learning to speak vocally, or remain unable to, impairing their ability to communicate with the people around them. Their social life suffers as a result.

Tobias Moser is a neuroscientist and otolaryngologist who heads a research group at the Max Planck Institute for Multidisciplinary Sciences in Göttingen, and the Institute for Auditory Neurosciences at the University Medical Center Göttingen. Moser is a specialist for synaptic hearing loss, which is an inner ear hearing disorder for which hearing aids are typically ineffective. At present, the only option for an infant suffering from synapse hearing loss is to have a cochlear implant to enable it to hear and speak later in life. Such an implant will ideally be implanted in the first year of life, before the child begins to speak. "Many synaptic connections in the brain expand and change during the first years of life," Moser explains. "If during this phase of development, the brain does not receive enough auditory stimuli transmitted from the ears, many such synaptic connections will not be made correctly. This deficit is difficult or impossible to compensate for later."

Our sense of hearing is complicated. Sound waves are conducted from the auricle into the outer ear canal and on to the eardrum, where they are picked up by the ossicles of the middle ear – the malleus, incus, and stirrup – and passed on to the spiral-wound cochlea in the inner ear. "Up to this point, microsurgery has been so successful in treating disorders with impaired sound transduction that the patient doesn't even need a hearing aid," says Moser. However, in 70 percent of cases the cause of hearing loss lies in the inner ear or auditory nerve.

Transmission to the inner ear

The spiral-shaped cochlea in the inner ear features four rows of sensory hair cells; their hair bundles protrude into the fluid-filled interior of the cochlea. Sensory tissue is set in motion by the mechanical vibrations transmitted to the cochlea from the ossicles, thereby deflecting the hair bundles of the sensory cells by the tiniest fraction of a millimeter. That suffices to activate the sensory hair cells. The outer three rows of sensory hair cells amplify these mechanical vibrations for faint sounds. The inner row transmits the sound information from its synapses to auditory nerve cells, which carry the information to the brain as a series of nerve impulses. Every individual is born with a limited number of sensory hair cells and auditory nerve cells. These have to last a lifetime, as the body cannot replace them. "Noise and age are the probable main causes for hair cells, synapses and, eventually, auditory nerve cells dying off," Moser explains. When exposed to 100 decibels or more for long time, at a disco club, for example, sensory hair cells are likely to be damaged or destroyed. Furthermore, some antibiotics or cancer drugs can cause hearing loss, which may be temporary or permanent.

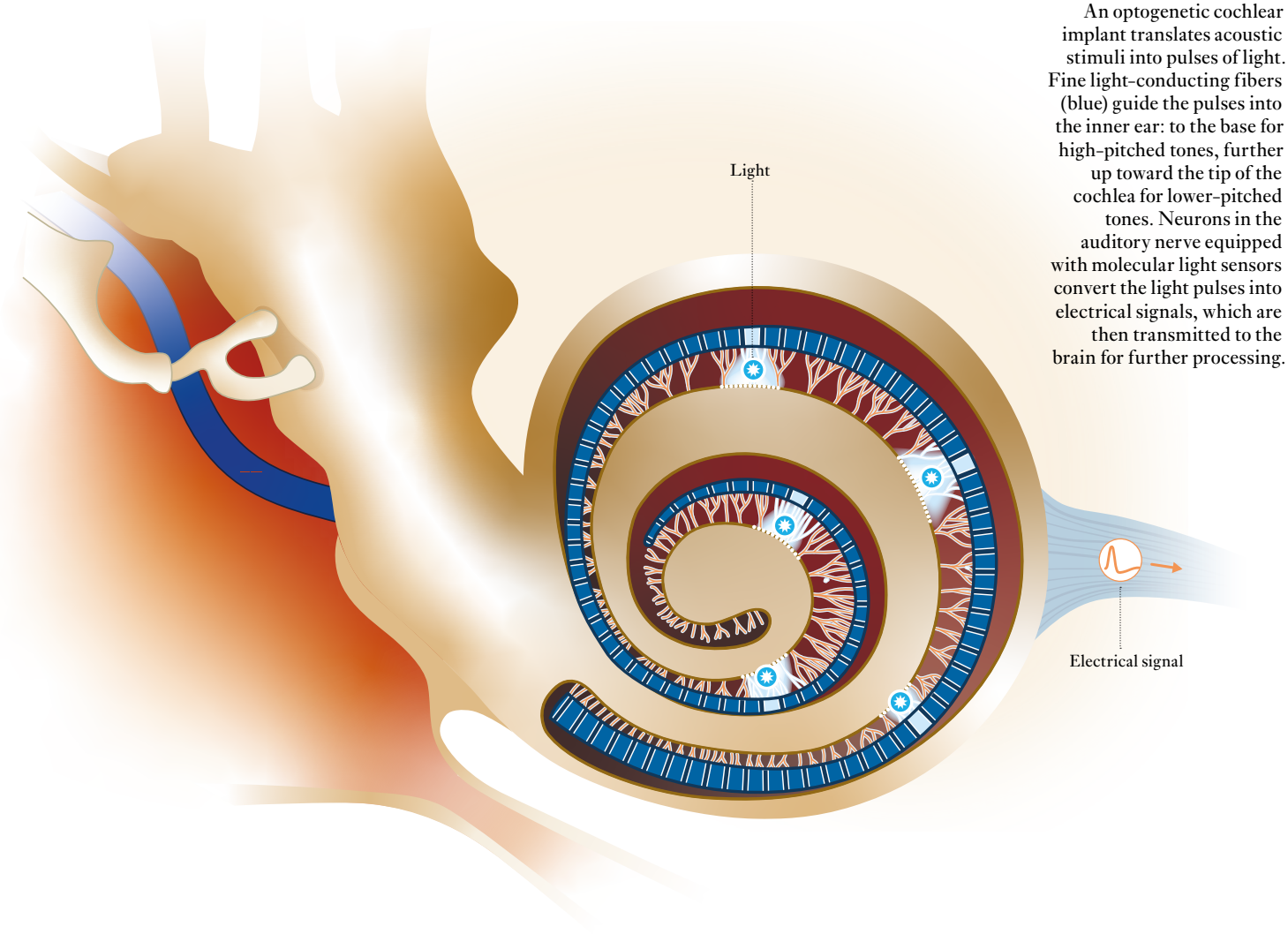
Cochlear implants are used for children who are born deaf as well as for adults who develop profound hearing loss or deafness. These implants take over the function of the cochlea, bypassing the sensory cells to directly stimulate the auditory nerve cells. In the surgical procedure, an electrode carrier with 12 to 24 electrodes (depending on the model) is implanted into the cochlea, and an electrical stimulator with receiving coil and magnetic coupling is placed in the temporal bone behind the ear. A speech processing unit inductively linked to the implanted device breaks down sound into its various frequencies and then transmits frequency, time, and volume data to the stimulator. The patients have to relearn how to hear using the cochlear implant because the artificial signal provided to the nerve is rather limited. "Many patients say they perceive a whooshing, metallic sound at first." Moser describes patients' initial impressions after the surgery as follows: "Speech is often difficult or impossible for them to understand. It may, for example, sound like someone is talking to them from behind a wall: they can hear that someone is saying something, but are unable to understand what. Even after months of practicing, in many cases it is still hard for patients to tell the difference between a spoken question and a statement, as they are unable to perceive the intonation of what was said."

SUMMARY

Hearing impairments stemming from the inner ear can be partially corrected using a cochlear implant. Researchers are currently developing optogenetic implants to afford a better hearing perception than is possible with today's electrical implants.

A new generation of optical cochlear implants will be able to transmit more frequencies for improved hearing. The first human trials are slated for 2026.

The patient and his/her relatives always have extensive consultations with doctors, engineers, and speech therapists before undergoing the operation. "Those unwilling or incapable of practicing intensively for a year or more should not go for an implant," says Moser. But even after doing intensive listening training, things never get back to the way they used to be. "The patients will always have difficulty understanding speech in everyday situations where there is background noise, and/or with multiple conversation partners. Melodies are also difficult for them to recognize." After insertion of a cochlear implant, the auditory experience of listening to a Sergei Rachmaninoff piano concerto or a Whitney Houston song will not be the same at all.



An optogenetic cochlear implant translates acoustic stimuli into pulses of light. Fine light-conducting fibers (blue) guide the pulses into the inner ear: to the base for high-pitched tones, further up toward the tip of the cochlea for lower-pitched tones. Neurons in the auditory nerve equipped with molecular light sensors convert the light pulses into electrical signals, which are then transmitted to the brain for further processing.

CHART: GCO ACCORDING TO MOSER / INSTITUTE FOR AUDITORY NEUROSCIENCE

At his office at University Medical Center Göttingen, Moser frequently talks to patients who are unsatisfied with the results they are getting from "electrical hearing". Such a problem can be a source of despair for professional musicians in particular. Moser's hope, then, is that the optical cochlear implants his research team has been working on since 2007 will be a success. The concept is to have sound information transmitted by light rather than electrically as light can be better confined in space promising better frequency selectivity. If feasible, this technology would truly be a breakthrough, rendering the audial perception of speech and music much more natural and rich in nuance.

The work of researchers at the Max Planck Institute for Biochemistry in Martinsried laid the foundations for this technology back in the 1970s, when Dieter Oesterhelt and his team discovered ion pumps within the cell membrane of bacteria which are activated by light. Then, around the turn of the millennium, Peter Hegemann of the University of Regensburg (now at Humboldt University of Berlin) in collaboration with Georg Nagel (now at the University of Würzburg) and Ernst Bamberg discovered light-sensitive ion channels in green algae while working at the Max Planck Institute for Biophysics in Frankfurt. These channels form the basis for optogenetics, a new research field that is enabling advances in how scientists unravel the mysteries of how cells and organs work. Optogenetics are of particular use in neurosciences. Outside of the eye, nerve cells are insensitive to light. In order for these cells to be activated by light, they first have to be equipped with a corresponding sensor. The light-sensitive ion channels originally deriving from algae cells are utilized for this purpose. Researchers first introduce the genetic blueprint for these proteins into the nerve cells of the auditory nerve via gene therapy techniques. Harmless, non-reproductive viruses are utilized as gene shuttles, which bind exclusively to the nerve cells in the auditory nerve and then place the gene for the channel protein in the cell nucleus of the nerve cell. The nerve cells then integrate the light sensor into their membrane. When the sensor detects light, it opens its floodgates so that ions flow in, electrically activating the cell. As with a conventional electrical cochlear implant, sound is broken down into frequency bands –

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but many more and finely defined ones in this case. Sixty-four optical fibers corresponding to the frequency bands then conduct light into the inner ear, with high frequencies fed to the base of the cochlea and lower frequencies further along the coils of the cochlea to its tip. "The brain knows that activated nerve cells at the base of the cochlea mean high-pitched sounds, and that activated cells at the end mean low-pitched hums. All we have to do, then, is ensure that the optical fibers attach to the right places on the cochlea to activate the nerve cells matching the particular sound," Moser elaborates. These implants thus deliver an auditory perception even when there are no more intact sensory cells left.

Pitch differences are easily distinguishable

Initial testing via computer simulation and trials with rodents has demonstrated that the technology works. At low and medium volume levels, frequency selectivity is near to that of normal hearing. Now Moser and his team intend to test out the new implants on common marmosets at the Primate Center in Göttingen. These monkeys are real chatterboxes, much like humans are, which plays into research. Marmoset calls are played from a loudspeaker, which only has as many frequencies as an optical cochlear implant is capable of. "Despite the limited frequencies, the monkeys recognize the calls and respond, which suggests that new implants can communicate communication sounds in an understandable way," says Moser. As the next step, the research groups led by Marcus Jeschke, a junior research group leader at Göttingen, intend to insert optical cochlear implants in monkeys to find out whether they are still able to recognize calls from their fellow monkeys.

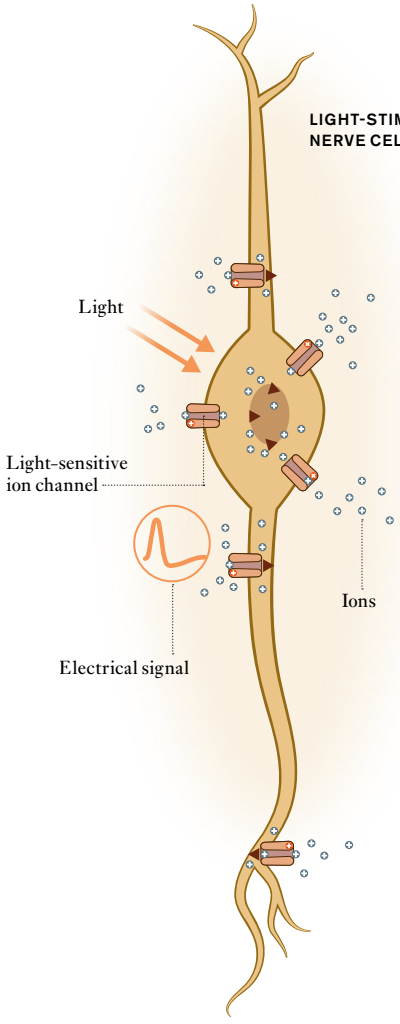
Moser and his team will have to fine-tune the technology before initial human clinical trials can commence in 2026. The implants' energy consumption needs to be reduced, and time and frequency resolution need to be optimized. There is one person who will be particularly happy when the trials start, even if he cannot take part in them himself: Fadhel El May, one of the doctoral researchers working with Tobias Moser. Hearing-impaired from birth, El May grew up wearing hearing aids. Then at the age of sixteen, he received an electrical cochlear implant.

We asked him about how the implant changed his life. "At first, I was shocked at how little I was able to understand. But after six months, my brain became able to understand language. If I were to switch off the implant today, I would be totally unable to follow a group conversation," relates El May, who studied engineering in Lausanne and Boston. Now able to follow discussions in larger groups, he still prefers talking one-on-one. "It's exhausting to me when there are multiple people talking at the same time. I sometimes will just have to leave the conversation."

He doesn't want to get a cochlear implant for his other ear, as he explains: "My hearing is worse in the ear with the hearing aid than in the ear with the implant, but when listening to music I am able to enjoy rich sound and hear high frequencies. I wouldn't want to give that up!" El May has now started taking piano lessons, and the only difficulty he has encountered is that he is unable to hear the difference between chords and individual notes, making him unable to correct an improperly played chord. Despite their drawbacks, cochlear implants have at least one small advantage over natural hearing: El May can use them as headphones. The implant automatically connects to his smartphone via Bluetooth, allowing him to make phone calls undisturbed by ambient noise, because he has his "EarPod" right in the ear itself.

www.mpg.de/podcasts/sinne (in German)

CHART: GCO ACCORDING TO MOSER / INSTITUTE FOR AUDITORY NEUROSCIENCE



In order for an auditory nerve cell to perceive light pulses and transmit the information contained therein via aural impression, the cell has to be genetically modified so that it produces light-sensitive ion channels and integrates these into its cell membrane. Electrically charged atoms flow through these channels when exposed to light. The inflowing ions cause the creation of an electrical signal which the nerve cell transmits to the brain.

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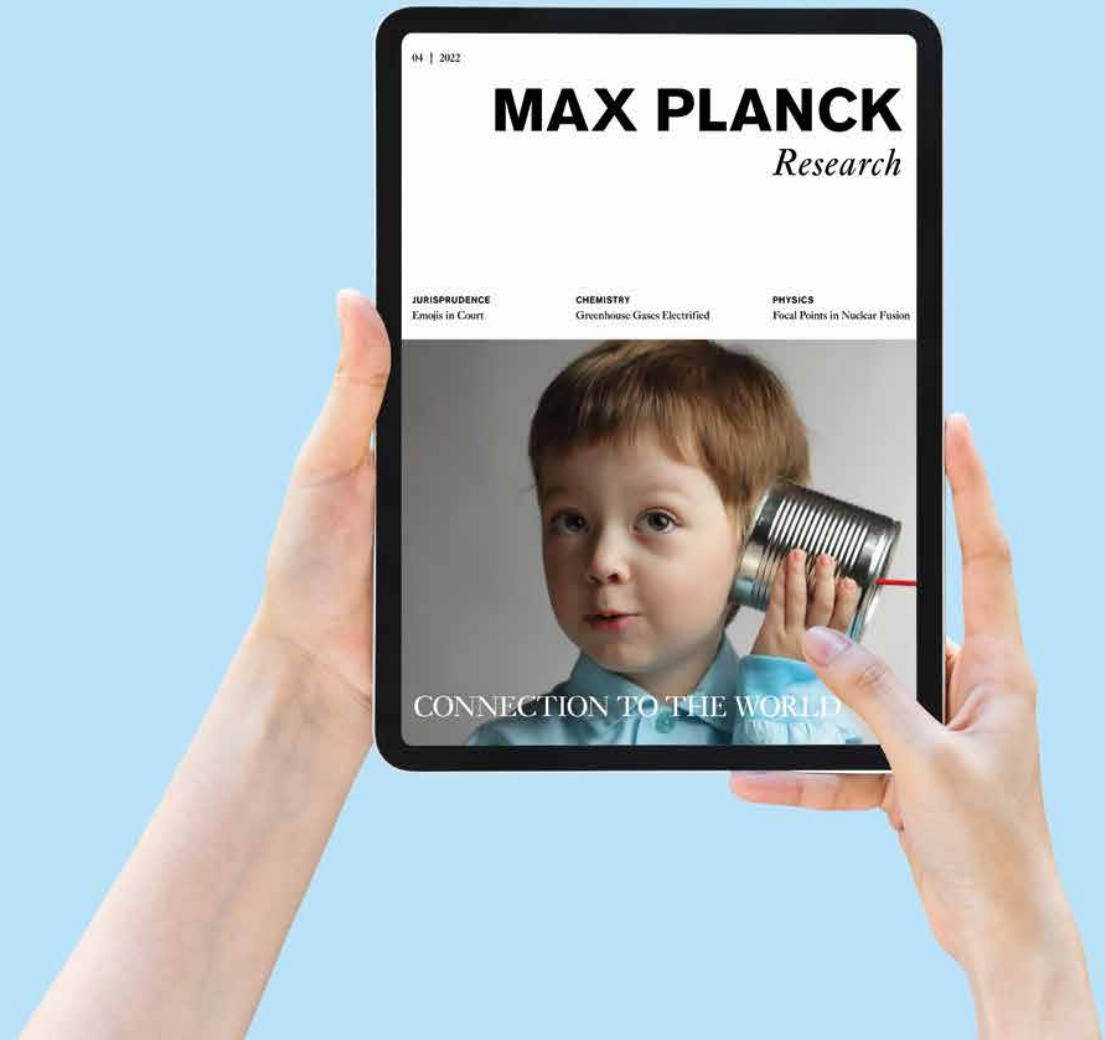

Unmistakably a rodent: Ansell's mole-rat *(Fukomys anselli)* is one of about a dozen species of African mole-rats. Its powerful incisors are constantly growing. The animal uses these when digging its tunnels to loosen the soil, kicking it backwards with its front and hind legs.

PHOTO: CHRISTOF SEELBACH FOR MPG

RODENTS WITH AN INNER COMPASS

TEXT: ANDREAS LORENZ-MEYER

Magnetic fields have no smell or taste, they are invisible, and they do not make any noise. As a result, we humans are not able to sense them on our own. The African mole-rat, on the other hand, has a magnetic sense or magnetoreception that it uses to find its way in the darkness. Pascal Malkemper and his team at the Max Planck Institute for Neurobiology of Behavior – caesar in Bonn are studying how this subterranean rodent senses magnetic fields.

As soon as the light goes on in the room with the mole-rats, the rustling begins. Every so often, an elongated body with light brown fur emerges from the tunnels and chambers in the cages, before disappearing again. There is a sudden thumping sound. "Those are warning signals," whispers Pascal Malkemper. "See this animal in the tube here! It makes undulating movements with its body, creating vibrations." The message does not go unanswered: a conspecific appears at the other end of the tube and responds by thumping.

The African mole-rats' room is full of cages, of which plexiglass tubes always connect two. The temperature is 26 degrees and the humidity is over 60 percent, matching the conditions underground in Zambia. This species is not found anywhere else in the world. The cages are designed to provide for the rodents' habitat requirements. The animals live in family groups and move around for their entire lives in tunnels, simulated by the tubes. The cages provide a latrine chamber, a sleeping chamber, and a food chamber. There are pieces of potato or carrot to eat, and sometimes apple too. However, there is no need for a water dispenser, because these African mole-rats do not drink. They take up all water through their food.

In the wild, the animals inhabit underground tunnel systems that can be several kilometers long. They live in permanent darkness and yet they find their ways perfectly fine in this maze of narrow passageways. They head for the various chambers with instinctive certainty – and they are intimately acquainted with the location of the food chamber where they stash the roots and tubers.

Eyes, noses, and ears help guide the African mole-rats only to a limited extent in their underground burrow system. To find their way, the animals use a special sense called magnetoreception. It has been known for some time that these creatures can sense the earth's magnetic field. This ability is not unique within the animal kingdom as fish, turtles, amphibians, and bats have it too. Migratory birds are also guided by the earth's magnetic field, and their magnetic sense is well studied. It is probably located in the eye.

Birds have what is called an inclination compass. This means that they sense only the inclination angle at which the magnetic field lines meet the earth's surface. At the equator, this angle equals zero, and the farther a bird flies to the north or south, the larger the angle becomes. As a consequence, birds cannot distinguish between the magnetic south and north poles. They are either flying towards a pole or towards the equator. Little is known so far about magnetoreception in mammals, but the mechanism appears to be fundamentally different from that in birds. African mole-rats have a polarity compass that, like a compass needle, is oriented to the two magnetic poles of the earth. While the birds' magnetic compass requires light, that of the mole-rats works even in complete darkness.

Pascal Malkemper chose the African mole-rats (of the genus Fukomys) because they are the only known rodents to use the earth's magnetic field for orientation. It is still uncertain whether their relatives, the naked mole-rats (which are kept in many a laboratory), can likewise sense magnetic fields. Keeping African mole-rats is also a bit easier than naked mole-rats because, thanks to their fur, they are better able to maintain their body temperature and because their colonies of two to 12 individuals are considerably smaller than those of the naked mole-rats, which can consist of as many as 300 animals.

"Magnetoreception seems to occupy an inferior position in the hierarchy of the senses."

PASCAL MALKEMPER

Optical sagittal section through the African mole-rat brain. In the cerebral cortex, the researchers came across neurons (arrows) that might be involved in processing information from the magnetic sense.

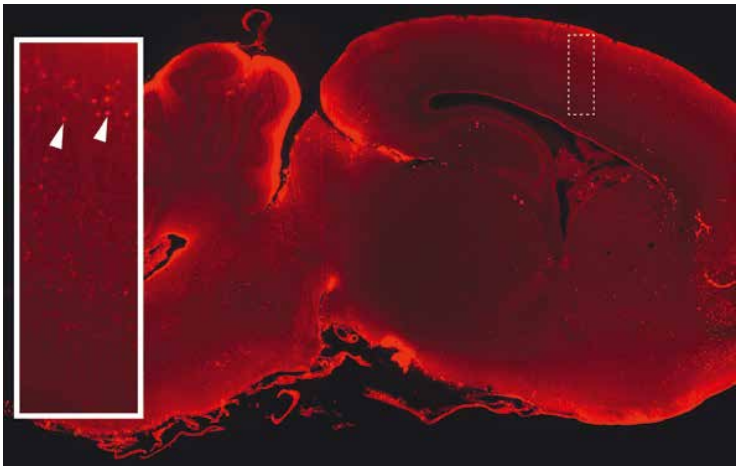

IMAGE: PASCAL MALKEMPER/MPI FOR NEUROBIOLOGY OF BEHAVIOR

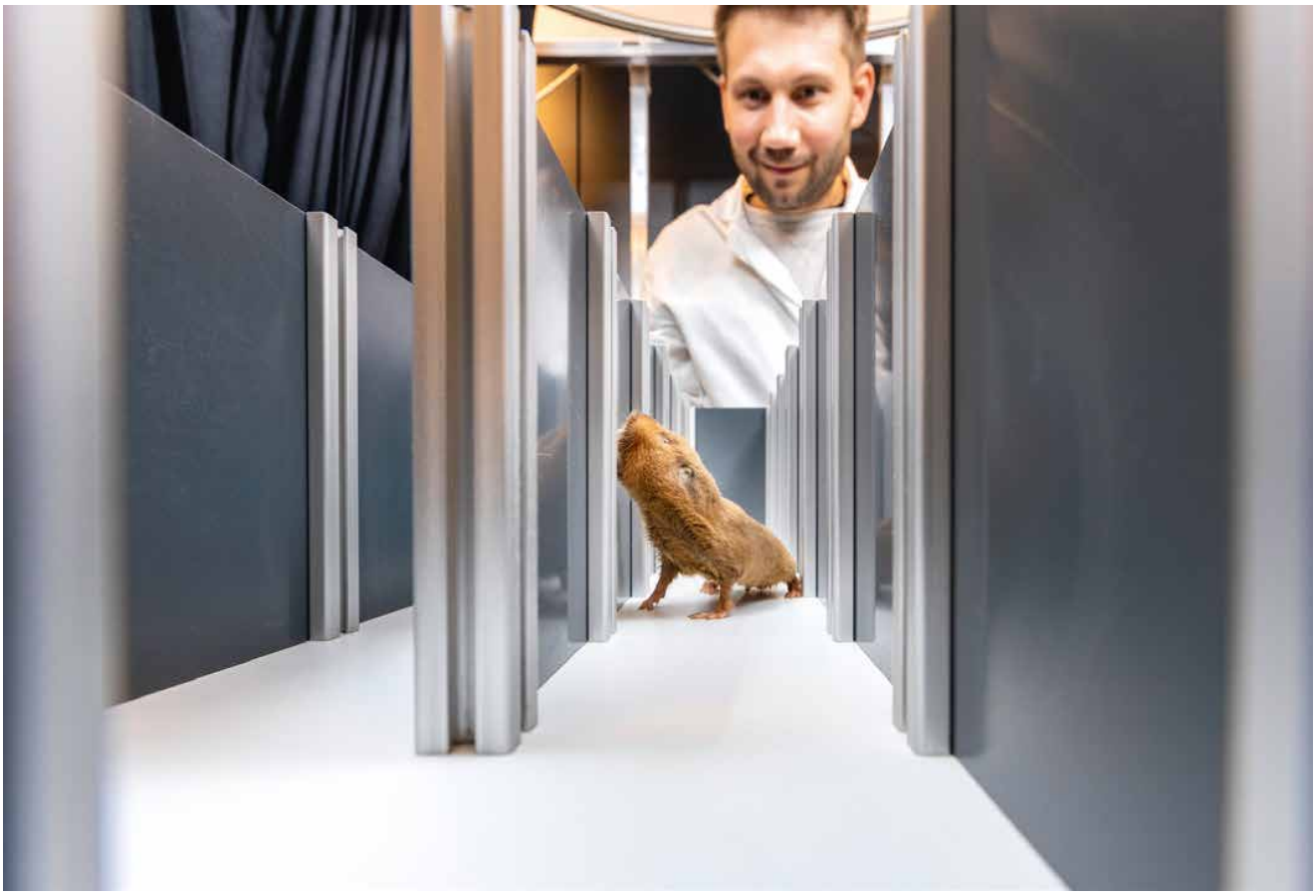

PHOTO: CHRISTOF SEELBACH FOR MPG

Pascal Malkemper is investigating the orientation capabilities of African mole-rats in a maze. The corridor system is located in an artificial magnetic field, which the animals use for orientation.

Pascal Malkemper opens a heavy steel door and enters a small room. On a table inside is a maze, with corridors that the researchers can open and close using flaps. The room is filled with a construction of rods and struts, which surrounds the table. "Many kilometers of copper wire are wound up in this coil system. When current flows through these wires, a magnetic field is generated within the coil that we can control precisely. It allows us to create artificial magnetic fields of all kinds," explains Malkemper.

Virtual reality for mole-rats

During the experiments, the researchers offset the real geomagnetic field of the earth with magnetic coils, at the same time simulating a new geomagnetic field. In addition, black curtains shield the miniature maze, thus preventing the animals from being guided by visual stimuli in the room during an experiment. The maze is also isolated from noises and vibrations; the rodents should not be distracted by anything. Since they could even be disturbed by odors, the chamber is meticulously cleaned after each run. "So it's a low-stimulus environment, except for the artificial magnetic field. This way, we ensure that our measurements can be attributed solely to the animals' magnetic sense," Malkemper explains.

Like most creatures, African mole-rats always use all of their senses. In many cases, if they hear or smell something, they prefer to orient themselves to this rather than to the magnetic signals. "Magnetoreception generally seems to occupy rather an inferior position in the hierarchy of the senses. One reason for this could be that the signal-to-noise ratio is low due to the low intensity of the earth's magnetic field."

Malkemper's team was able to show that the African mole-rats use their magnetic sense for orientation by means of a simple experiment in the maze. Animals that have previously learned to locate a chamber con-

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Well placed: the research group, consisting of Runita Shirdhankar, Alessia Atzori, Pascal Malkemper, Georgina Fenton, Li Zhang, and Sybille Wolf-Kümmeth.

PHOTO: CHRISTOF SELBACH FOR MPG

SUMMARY

The research group wants to understand where and how magnetic information is processed in the brain of the African mole-rat.

Initial findings indicate that the sensory cells for magnetoreception are located in the eyes.

taining food within the maze take much longer to find their way to the food if the artificial magnetic field around the labyrinth is changed so that their orientation is confused. However, it is not only the direction of the earth's magnetic field that African mole-rats might use as an aid to orientation in the wild. A question that remains unanswered is what role is played by local magnetic anomalies that are caused in nature by iron ores, for example. They might be used by the animals as magnetic landmarks. In the magnetic field chamber at the Max Planck Institute in Bonn, magnetic anomalies such as these can also be created. "We want to test whether anomalies of this sort make it easier for the animals to navigate within the labyrinth, like markings or signs on the walls of a maze would help to guide a person. For this purpose, we can alter the magnetic field in real time, dependent on the position of the animal in the maze – sort of virtual reality for mole-rats," says Malkemper.

Pascal Malkemper and his team want to find out how the African mole-rats sense the magnetic field and which regions of the brain process the signals. To do this, the researchers measure the activity of neurons in a brain region known as the hippocampus, which is very important for spatial orientation. This is where information is transferred from short-term memory to long-term memory – so the hippocampus is sort of the main memory of the brain.

PhD student Runita Shirdhankar investigates so-called place cells in the hippocampus and analyzes them. Each of these neurons or place cells is active at a specific position in the maze. "The question is whether the cells become active at a different point if we change the magnetic field only. Then we would know that the place cells are receiving information from another type of cell in the brain that processes the direction of the magnetic field. We are looking for these cells," explains Malkemper. When searching for these cells in other regions of the brain, Malkemper and his team make use of proteins that are expressed whenever a neuron is active. To make them visible, the researchers label them with fluorescent dyes and then make the brain transparent. Under the microscope, the neurons activated by the magnetic field then reveal themselves by their glow. "Initial results indicate that several regions are involved in the processing of magnetoreception, including the hippocampus and the superior colliculus in the midbrain. That's where information from different senses is integrated in other mammals," says Malkemper.

Cells with particles of iron

Starting from these areas, Malkemper and his team want to find the sensory cells – that is, the actual compass organ – that the African mole-rats use to sense a magnetic field. They are seeking cells that contain tiny magnetic particles of iron. These magnetic needles made of iron oxide, however, are only a few millionths of a millimeter in size. Thus, instead of looking for them directly, the researchers want to be led from the brain areas to the sensory cells. Dyes highlight the neurons and their processes. The researchers are aiming to follow the way through these circuits, from one neuron to the next, right to the origin of the magnetic signal – the magnetoreceptor cells. The team already has an initial indication of the location of the magnetoreception; temporarily anesthetizing the eyes also disrupts the magnetic sense. "So the eyes appear to somehow be involved in sensing magnetic fields," says Pascal Malkemper.

Once the sensory cells for the magnetic information have been found, the researchers want to investigate how they work and identify the genes that enable the perception of magnetic fields. These would also reveal to researchers how magnetoreception developed in mammals. It could also help us to better assess whether and how the electromagnetic fields in the modern, human-influenced, nature affect animals. And finally, the African mole-rats in Malkemper's lab could provide answers to the question: do primates, including we humans, also have an unconscious magnetic sense?

"The eyes are probably involved in sensing magnetic fields."

PASCAL MALKEMPER

www.mpg.de/podcasts/sinne (in German)

When he was still in primary school, Krishna Gummadi learned to play musical instruments and studied programming. He soon gave up on music, but programming turned out to be his calling. These days, as director at the Max Planck Institute for Software Systems in Saarbrücken, he is researching, among other things, why artificial intelligence often makes decisions that are just as discriminatory as the ones humans make, and how this can be prevented.

TEXT: TIM SCHRÖDER

When the first algorithms that came close to matching human intelligence appeared on the market in the early 1990s, they sparked great enthusiasm. Banks used them to take on the time-consuming task of deciphering handwriting on cheques, while others recognized objects in pictures for the first time – soccer balls on grass, for example. Computers were no longer simply processing instruments, mathematical robots that, like a chess program, simply played through thousands of variations in a matter of seconds. Now they could actually recognize and interpret things. Since then, algorithms have begun to take a lot of decisions away from humans, and this is often controversial: they filter out the best candidates from applications for a new position. Other algorithms sense the preferences of Internet shoppers in order to place targeted advertisements. Artificial intelligence (AI) is thus encroaching more deeply than ever into our everyday lives, and our society. "Artificial intelligence has spawned socio-technical systems that have a significant impact on how we live together," says Krishna Gummadi. "What interests me is the problems this brings and how we can solve them."

Krishna Gummadi is the director of the Max Planck Institute for Software Systems in Saarbrücken. He has focused for many years on distributed computing networks, cloud computing, and secure data traffic on the Internet, and for some time now, he has been particularly interested in the merging of society and technology. He calls this "social computing". The extent to which the decisions of "socio-technical systems" are unjust and can disadvantage people is a topic of increasingly frequent debate – including among the public and in the media. Krishna Gummadi examines these algorithms closely.

A few years ago, the public learned about the AI software COMPAS (Correctional Offender Management Profiling for Alternative Sanctions) from the USA, which was supposed to reliably calculate the recidivism risk of offenders. To evaluate this risk, the software used not only information about previous convictions and the severity of current offense, but also personal data such as the age of the offender. Though the software designers denied using additional data, the program also accessed criminal records of close relatives, information about alcohol and drug abuse within the family, social ties, friends, and the person's financial situation. This data was further supplemented by character traits such as tendency toward anger and aggression. In many states, judges handed down particularly harsh sentences based on poor COMPAS scores. Experts from the research network ProPublica examined the COMPAS results more closely – and then published a study that made headlines. It showed that the COMPAS algorithms gave defendants of color a higher risk of re-

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VISIT TO

KRISHNA GUMMADI

PHOTO: ANNA ZIEGLER FOR MPG

Cross-border researcher: Krishna Gummadi carries out research at the interface between computer science and social sciences. For example, he investigates the social impacts of artificial intelligence.

PHOTO: ANNA ZIEGLER FOR MPG

Programmed for fairness: sometimes artificial neural networks make discriminatory decisions. Krishna Gummadi is expanding algorithms to prevent this in the future.

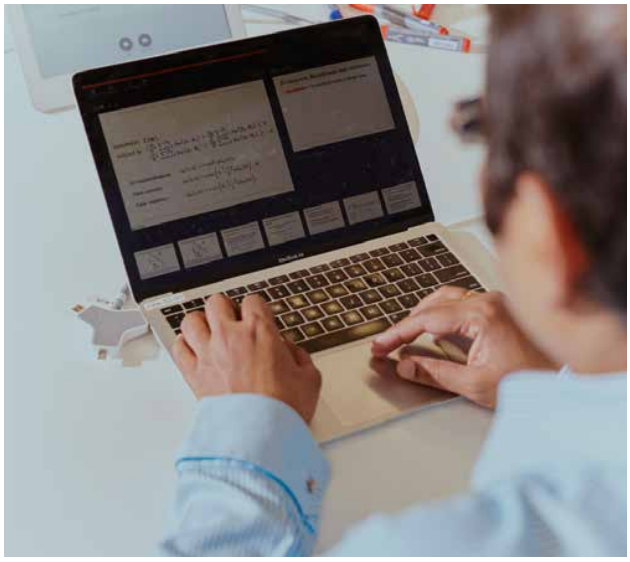

PHOTO: ANNA ZIEGLER FOR MPG

offending than was actually the case. The reverse was true for white defendants: COMPAS gave overly positive predictions more often. AI algorithms like the ones used for COMPAS are based on processes of machine learning.

The algorithms are constantly fed with data from reality and trained to then make decisions independently. Yet these decisions are only ever as good and accurate as the data with which the algorithms are trained. A well-known example is an algorithm that learned to recognize soccer balls in pictures. An analysis of the software showed that the algorithm identified soccer balls by the crIteria "black and white," "hexagonal", and "green" because many of the photos showed grass – a correlation that has nothing to do with the characteristics of soccer balls. The soccer ball algorithm makes for a good anecdote, but the COMPAS algorithm had dire consequences because it discriminated against people of color. Ultimately, COMPAS had been trained with data that had been gathered by human beings – and quite obviously, these were so prejudiced that they disadvantaged such people. "We call this kind of thing a bias, a distortion of the data," says Krishna Gummadi. "Basically, the developers of COMPAS meant well. They wanted to make risk assessment more objective by letting the computer do the work." Humans can be biased, but the computer is not – or so they thought.

There was a similar situation a few years ago with a US software program that was supposed to automatically select suitable employees from a large number of applicants. It was found that it suggested women as suitable candidates significantly less often. "We want to understand how the algorithms work so that these kinds of weaknesses can be ironed out," says Krishna Gummadi. When asked if he is concerned with discrimination because he may have been a victim of it himself, he shakes his head. "No, I'm just interested in a lot of different topics – combining social aspects and computer science is something I really enjoy." Krishna Gummadi often smiles when he discusses his work. "I really enjoy working and actually don't have all that many hobbies."

Krishna Gummadi grew up in the Indian city of Hyderabad. It was important to Gummadi's father that his two sons receive a good education. He had been the first in the family to go to university, completing a bachelor's degree in engineering. At the time, he only had one option: after his bachelor's he had to earn money. Krishna and his brother, meanwhile, were to go further in life. "Our parents made sure we were educated as broadly as possible," he recalls. "Our father enrolled us in various courses when we were still in primary school – guitar lessons, for example, as well as flute lessons and a computer science course, where we gather our first experience of programming." It wasn't long before he gave up the flute and the guitar, but the computer science grabbed him. After finishing school, he – along with around 200,000 other Indian high school graduates in his year – took the university aptitude test, which included questions about various subjects. He came 18th overall. "That was a huge bonus, because the first 20 are free to choose the subject they study." He chose computer science and engineering and moved to Chennai, where he did his bachelor's degree at the Indian Institute of Technology. A master's and doctorate followed at the University of Washington in Seattle, where he worked as a research assistant for several years.

Ending up in Saarbrücken was merely coincidence. "I applied to several universities for tenure in 2005 – including Rice University in Houston. That put me in touch with Peter Druschel, who was working there at the time." Peter Druschel is the founding director of the Max Planck Institute for Software Systems. He was impressed by Gummadi's work and asked him whether he could picture himself moving to Saarbrücken. At first, Gummadi was hesitant about relocating to Germany, but he eventually agreed after Peter Druschel offered him a tenure track position – a permanent role that can lead to a professorship. At the time, no one could have foreseen that Krishna Gummadi would one day become director of the Institute – or even that he would stay in Saarbrücken for so long. "But the city is incredibly international, perhaps because of its proximity to France. And thanks to the other computer science institutes on the campus, there's a high density of professional colleagues here." Together with his wife, he lives on the Saar in a little village, which is next to the border with France. And there's another thing he particularly likes – the region's cuisine. As things stand, Krishna Gummadi is here to stay.

And that's despite the fact that even after so many years in Germany, he still prefers to conduct longer conversations in English. "The Institute is so international that everyone speaks English here, which means you don't practice much on a day-to-day basis." He speaks German, of course, when he does his shopping, but because his wife is also from India, there is no reason to speak it at home. When a new

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doctoral researcher recently asked if it was possible to survive in Germany without speaking German, the people in his working group laughed. "I'm the best example of that," they said.

For the past five years or so, Krishna Gummadi has been getting more and more involved with "social computing". With the development of AI algorithms that use machine learning, you give the computer a goal and then just let the algorithm do it. "We call this the declarative approach, where I just define the goal – for example, 'Pick the best applicant.' The path through the individual development steps is of no concern," says Krishna Gummadi. The tools used in this process include so-called deep neural networks. Although these algorithms and neural networks deliver results, it is no longer possible to see how the computer made its decision. The process is like a black box, and this becomes problematic, among other things, when women are less likely to be invited to a job interview because the computer filters them out beforehand.

"Just a few years ago, computer scientists doubted that such cases were computer engineering problems," says Krishna Gummadi. "Now it's clear that with socio-technical systems, information science is one of the tools we need to solve problems." Instead of pursuing just one goal in a "utilitarian" fashion as in the past – aiming for an outcome with the lowest possible error rate – in the future, additional goals must be defined, such as preventing unequal treatment and discrimination. The challenge today is to also teach the computer the social context.

One of the definitions of discrimination is: "Discrimination is the act of distinguishing between people on the basis of the groups, classes, or other categories to which they belong or are perceived to belong." Computer scientists must cast references such as "based on groups" or "belonging" into algorithms – an abstraction task that initially has nothing to do with bits, ones, and zeros. "We spent a long time thinking about how you can abstract discrimination in order to develop algorithms that will be free of discrimination in the future. In the process, we came up with the notion of envy-free," says Krishna Gummadi. Among other things, membership in groups becomes problematic when one is favored and the other disadvantaged, which can generate envy, he explains. And that can be expressed mathematically.

"Now it's clear that with socio-technical systems, information science is one of the tools we need to solve problems."

Krishna Gummadi's social computing goes beyond the topic of discrimination. He is interested in how algorithms work in "digital public spaces" – on platforms such as Facebook and TikTok or at online mail-order companies such as Amazon. In a recent study, he and colleagues at the Indian Institute of Technology examined the extent to which Amazon's website algorithms discriminate against vendors. Amazon has long been more than just a mail order company. They also manufacture their own products – and offer them in competition with established manufacturers. Gummadi's team examined how often on the Amazon site the window "Other customers also bought..." displayed Amazon's own products or the goods of other manufacturers. They focused on batteries and backpacks, and the results are sobering: in the case of backpacks, Amazon displayed its own products twice as often. This is admittedly not illegal, but Amazon has another major competitive advantage: the company simultaneously acquires countless customer and market data, which are not available to the other providers. "In the long run, this can weaken the market position of the other providers and is basically a case for the regulators," says

Krishna Gummadi. "Amazon can't be both a player and the referee setting the rules." He also believes it is his duty to point out such abuses in a scientifically sound manner, but says it's up to others to take action.

Back in 2015, he and Emilio Zagheni, director at the Max Planck Institute for Demographic Research in Rostock, had already investigated what data Facebook manages in the so-called API, a programming interface, as part of a project together. Via the API, companies can place advertisements and leverage the browsing behavior of users and potentially interested parties. A whole universe of new data opened up for social science research and particularly, for demographic research. The researchers were able to study migration patterns, including migration of refugees during crises. When conducting the studies, Gummadi's team discovered a privacy vulnerability due to a bug in the API design. A malicious advertiser would be able to retrieve an explosive amount of people's private data, including their addresses, phone numbers, and all the personal information that came from databases to which Facebook is linked. "The amount of private data that was exposed here was staggering," says Krishna Gummadi. "Through the API, we had access to several thousand attributes." Together with his collaborators, Gummadi published a specialist article on the matter, and Facebook has since revised the API interfaces.

"It's funny," he says. "Social computing is a hot topic today – but bringing together social and technical aspects is basically old hat." For example, he says, many of the great computer scientists of the early days had a background in the social sciences – and only later tackled topics such as cognition or decision-making, paving the way for artificial intelligence. In this respect, he says, social computing has now come full circle. Two years ago, Krishna Gummadi organized a symposium for the Max Planck Society on the intersection of society and computer science. Interest was enormous. In just a short time, 270 participants from various Max Planck Institutes signed up.

And the volume of topics is also enormous. Krishna Gummadi and his colleagues are constantly coming across new aspects, but right now he is interested in how the algorithm of the social media platform TikTok works. TikTok delivers an endless stream of short videos. Without people clicking on videos or entering search terms, the platform learns about users' preferences in just a short space of time. How quickly does someone keep scrolling? How long does someone spend watching a video? After only about half an hour, the algorithm delivers videos that fit perfectly – and thus keeps users on the platform. "This leads us to yet other aspects of social computing," says Krishna Gummadi, "to the question of the extent to which the direct, often emotional appeal leads to addictive behavior, to depression or to loneliness." The beauty of working at the Saarbrücken Institute is the freedom to do research without having to deliver results right away, he says. "Here, my curiosity is given free rein – so I can take a detour now and again in subject matter, too."

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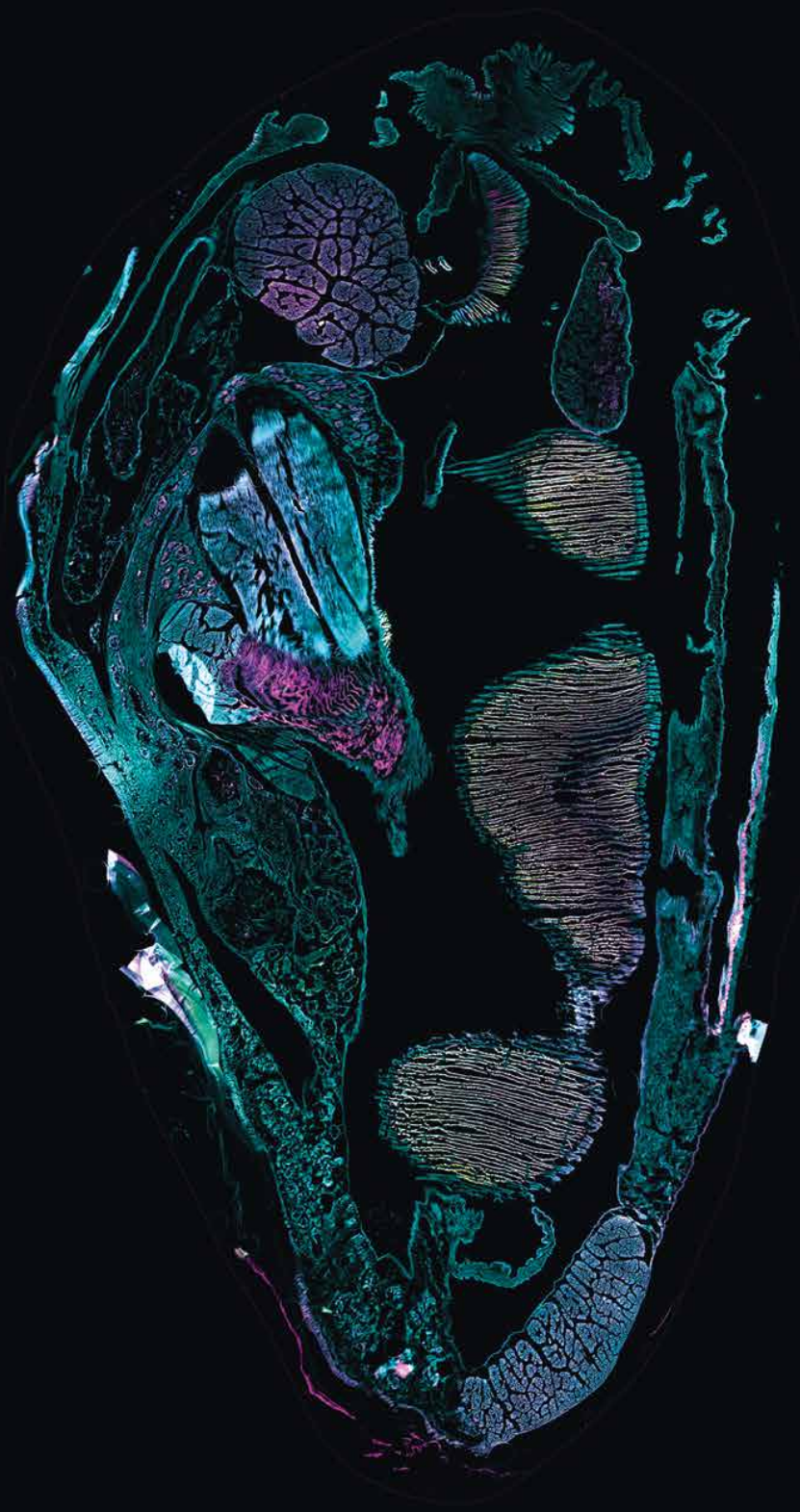
Bound by algorithms: social media platforms like the video platform TikTok are often programmed to cast a spell over users – the psychological consequences of this are still unknown.

PHOTO: ADOBESTOCK / NATTAKORN

IMAGE: MPI FOR MARINE MICROBIOLOGY / BENEDIKT GEIER / MAXIMILIAN FRANKE

DOUBLE TAKE



MAX PLANCK INSTITUTE FOR MARINE MICROBIOLOGY

The deep-sea mussel *Bathymodiolus azoricus* is a relative of the edible blue mussel. It inhabits so-called black smokers – towering vents on the seafloor from which hot, mineral-rich water flows out at temperatures of up to 400°C. Survival under such extreme conditions requires teamwork. The mussel harbors symbiotic bacteria inside it that are able to use methane or hydrogen sulfide from the hot springs to generate energy. These microscopic subtenants transfer part of the energy to their host and in return are housed in a protected environment where they are surrounded by water containing sulfur and methane. The picture on the left provides a view under the mussel shell. On the right, researchers at the Max Planck Institute for Marine Microbiology in Bremen have made the microbes visible. They form extensive colonies inside the mussel, which glow here in fluorescent light.

IMAGE: MPI FOR MARINE MICROBIOLOGY / BENEDIKT GEIER / MAXIMILIAN FRANKE

"EMOJIS ARE PUTTING THE LAW TO THE TEST"

INTERVIEW: BARBARA ABRELL

Digital communication is prone to misunderstandings – and that especially applies when emojis are used. The popular pictograms are frequently understood in completely different ways, depending on age, gender, or cultural background. They are, therefore, increasingly becoming a subject for courts – for example, when contracts are concluded by e-mail or a messenger service or when posts are perceived as defamatory. Matthias Pendl, Senior Research Fellow at the Max Planck Institute for Comparative and International Private Law in Hamburg, has been researching the role of emojis in (private) law considering judgements from several jurisdictions around the world.

Researching emojis isn't something immediately associated with legal scholarship. Mr. Pendl, what motivated you to devote yourself to this research topic?

MATTHIAS PENDL Actually, a concern at the beginning was whether my rather quirky research interest would be well received in professional circles. Yet there were a surprising number of prompts to pursue the topic: from my former boss, who used a 🙂 in his e-mails whenever I had done my work well, to the experiences I had while clearing out my home before moving from Vienna to Hamburg. Many of my ads on the classifieds portal "Willhaben", which is very popular in Austria, were commented on with emojis like 👍 or with various emoji faces. As a lawyer, I asked myself: were these binding agreements? Then came the lockdown, and I suddenly had time to research something new.

As a means of communication, emojis often replace intonation, gestures, facial expressions, and other elements of body language. What are their strengths and weaknesses?

Emojis are so popular because they enrich communication with emotional touches. The difficulty, however, is that interpretation is not entirely straightforward – and this brings us straight to the legal problem. One and the same emoji can be understood in different ways depending on the context.

Could you perhaps give us a few examples of typical misunderstandings?

Sure. I have younger brothers. One of them recently explained to me that the face with tears of joy emoji 😂 is no longer used at all by his generation – Generation Z. When he's amused by something, he now sends a skull ☠️ as a response, which means you're dying from laughter at what the other person said. I have advised him to be careful with this in WhatsApp – especially when he's sending messages to his grandparents… Communication between the sexes, meanwhile, frequently has implications in terms of labor law. Often, women no longer perceive emojis as funny, for example, when colleagues send them the supposedly harmless eggplant 🍆 emoji as a phallic symbol, or the peach emoji 🍑 as a suggestive reference to the human buttocks. A third example can be drawn from a recent email exchange with a guest researcher from China. I noticed that emojis I sent him didn't show up at his end at all. In addition to the misunderstandings that often occur when people from different cultures communicate,

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IMAGE: ADOBESTOCK / VILMOS

KNOWLEDGE FROM

A multifaceted emoji: is someone lost in thought here; is he thinking about what has been said, is he questioning it, or does he perhaps think that it's questionable? Depending on the context, one and the same pictogram is interpreted quite differently.

Whether contracts are concluded via e-mail or messenger app, the interpretation of emojis can become the key issue.

IMAGE: GCO ACCORDING TO MPG

Has a contract been concluded here? 👆

there are also technical hurdles in the use of emojis – especially when different e-mail programs are used.

What is the relevance of emojis in legal practice? Is there a trend you can observe?

Emojis are putting private law to the test: there is a growing number of court decisions in which emojis play an important role. This trend is evident in Germany as well, even though most of the published judgments in this country concern violations of personal rights or stem from labor law. One example is a case before the Regional Labor Court of Baden-Württemberg. The case concerned an extraordinary dismissal that was issued because of publicly viewable comments on Facebook. Among other things, it said in reference to a supervisor: "The fat 🐷 is going nuts!!! 😉 😜 😝" The court considered this to be a gross insult, but the dismissal had to be revoked due to the lack of a warning.

In matters like this, it makes sense that the courts are confronted with emojis. But do emojis also play a role in criminal law?

Yes, a big role, in fact. In the United States, there is an unfortunate number of reports involving threats of violence in schools through digital communication using emojis. In one case at the California Court of Appeal, for example, a minor had suggested in her tweets that she wanted to go on a rampage at her school. Her defense, that the numerous laughing emojis she had used were a sign that it was just a joke, was rejected by the court, which instead assumed that the threats were deliberate. Furthermore, the potential of emojis for making threats very often emerges after failed relationships. For example, a Frenchman, was reportedly given a custodial sentence for sending his ex-girlfriend a gun emoji 🔫, which the court considered a death threat. In California, a man was convicted of first physically abusing his former partner and then sending her the following text message: "You have 12 hours to find me, before I find you." And he supplemented the message with various emojis that showed, among other things, bombs 💣, guns 🔫, knives 🔪, and needles 📌.

Court rulings rarely depict the colorful pictograms; they simply use the word "emoji" – often written in square brackets – or "[laughing emoji]," "[sad emoji]," or "[astonished emoji]." What is the reason for this?

EMOJIS, EMOTICONS & CO.

Emojis and emoticons are similar only at first glance. Emoticons consist of dots, dashes, brackets, letters, and numbers and – read sideways – result in a symbol that reflects a certain facial expression. The term is composed of the words emotion for "feeling" and icon for "symbol." Well-known examples are the smiley face :-), the sad face :-(, the wink ;-), and the surprised expression :-O. In other cultures, completely different emoticons are often used; for example, Kaomojis in Japan, which also look completely different. A happy facial expression, for example, looks like this: ٩(◕‿◕｡)۶.

Emojis, on the other hand, are colorful pictograms or ideograms – such as 😘 and 👏. They are defined by uniform encoding, Unicode. This forms the technical basis for text and symbols in modern software and regulates their use in digital media. There are now also many animated emojis that, for example, roll their eyes or actively wink at you.

That is an important question to which I do not have a clear answer. I have never been a judge myself, so I simply don't know and can only make assumptions. It's probably just too cumbersome to include the colored pictograms – I know of only one case where a screenshot was used – especially since the judgments are mostly black and white when printed out.

Or because the judgment itself would appear less serious …

Yes, that may be a concern as well. Emojis are sometimes considered not formal enough for legal language use, but that's something I find problematic. If emojis are crucial in a case, it is important to know what they actually look like, otherwise essential information will be lost.

You have examined court cases from seven different countries – the USA, Canada, the UK, Australia, Germany, Austria, and Israel. Are there significant differences between the individual countries?

The data available is still too thin for a direct comparison. In Germany, for example, there have been hardly any studies on this so far, which is why I have attempted to fill this gap. In general, the discourse has progressed to different degrees: in the USA, in particular, but also in Canada, there is significantly greater awareness of the importance of emojis in communication. There – similar to Australia – the lIterature is also adopted in the judgments and the phenomenon is dealt with in more detail.

Social media platforms, messenger services, and even video platforms propagate the use of emojis, and some even reward it by giving preference to posts that contain emojis. Is our communication suffering as a result?

Personally, I have developed a very positive attitude towards emojis. Through the enrichment of written language with emotional elements, our communication gains more than it suffers. But you'll probably get different answers depending on who you ask.

What do you think of the minimalist tendency to respond to a message with just an emoji?

I don't see an overall trend here, but there are linguists who believe that emojis have the potential to form an alternative language. However, that – as far as I understand – is a very controversial field.

Many thanks for talking to us!

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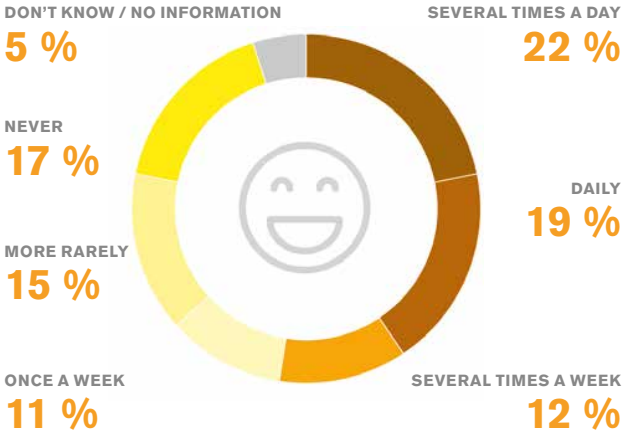
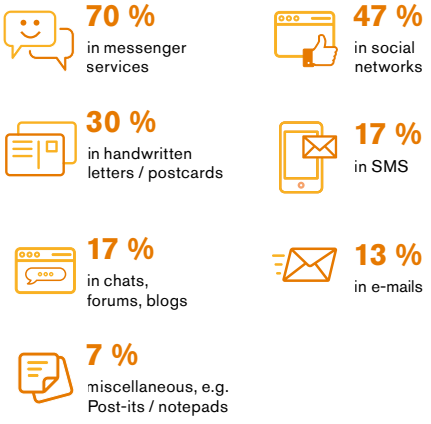
Use of emojis in Germany



The survey encompassed a total of 1004 people in Germany aged 16 and over.
Source: Bitkom Research 2021



The survey encompassed 788 people in Germany who use emojis; multiple responses possible.
Source: Bitkom Research 2021

The Bitkom association, which represents more than 2000 companies in the information and telecommunications industry, regularly conducts surveys on digital topics. The two surveys from the last year demonstrate how often Germans use emojis - not only in electronic media but also in handwriting.

IMAGE: GCO ACCORDING TO BITKOM RESEARCH 2021

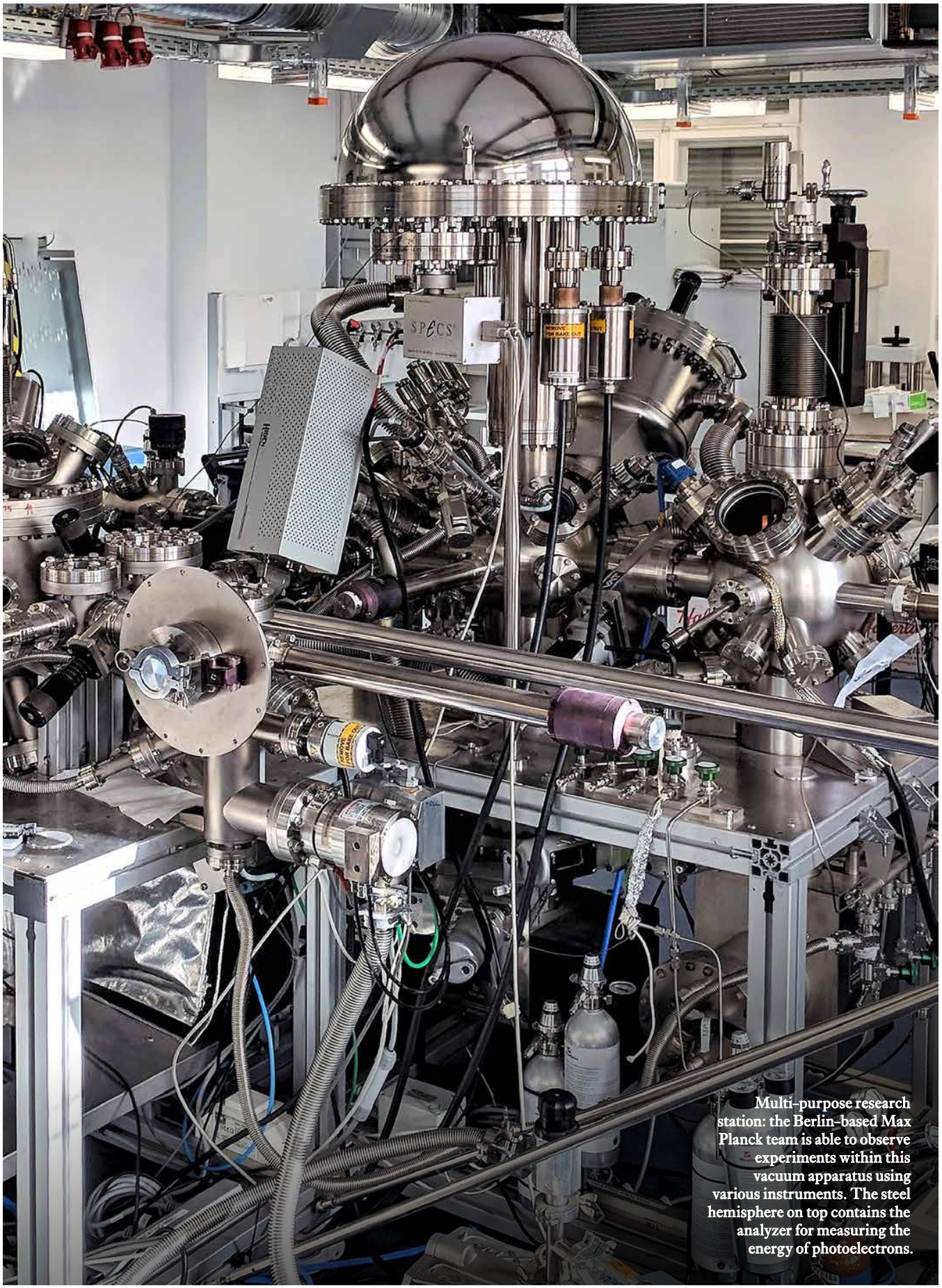


PHOTO: FRITZ HABER INSTITUTE OF THE MPS

Multi-purpose research station: the Berlin-based Max Planck team is able to observe experiments within this vacuum apparatus using various instruments. The steel hemisphere on top contains the analyzer for measuring the energy of photoelectrons.

GREENHOUSE GASES ELECTRIFIED

TEXT: KARL HÜBNER

In future, the greenhouse gas carbon dioxide could be used to create important chemicals and fuels. If this vision becomes reality, it would be a major step towards achieving a sustainable circular economy. The Interface Science Department of Beatriz Roldán Cuenya at the Fritz Haber Institute of the Max Planck Society in Berlin is working toward this very goal.

The concentration of CO_2 in the atmosphere is inexorably rising – which has well-understood consequences for the climate. Stopping this process is a task of mammoth proportions. Yet in some areas, such as waste incineration or cement production, it is almost impossible to avoid producing carbon dioxide exhaust. One option is capturing the gas at the point where it is released and disposing of it in underground storage facilities. Another possibility is to use it as raw material for synthesizing fuels and chemicals as a way of carbon recycling. Such CO_2-neutral production would have two positive impacts: avoiding direct CO_2 emission and reducing consumption of fossil raw materials.

Research groups around the world, including some at the Max Planck Society, are working on ways to utilize carbon dioxide as a raw material for the production of useful chemicals (see MaxPlanckResearch 3/2021). Indeed, the gas is already being processed industrially, together with hydrogen, to produce methanol – a raw material of major importance in the chemicals industry. Furthermore, a research group led by Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion, is collaborating with a team from Covestro AG to develop another special process. For several years now, a polymer has been partially derived from CO_2 that is used to produce foams used in mattresses (see MaxPlanckResearch 2/2019). The method reduces consumption of the crude oil from which the corresponding polymer component is usually extracted. Nevertheless, using CO_2 in chemical processes is no simple matter, because it is highly stable as a molecule. A substantial amount of energy has to be spent to make the molecule responsive, which is why high pressure and high temperature are required for such methanol synthesis. There is another approach, however: using electrical instead of thermal energy to get CO_2 to react. This represents an electrocatalytic route comparable to the electrolytic generation of hydrogen from water. Ideally, of course, the electricity required for the process should be "green" – for example, derived from solar or wind power.

Carbon monoxide (CO) is a possible by-product of CO_2 electrolysis. It is possible to obtain numerous important basic chemical substances from this gas, in combination with hydrogen (which should also be produced using renewable energies). What's more, the necessary industrial infrastructure for this already exists. A further idea is the direct electrocatalytic production of some of these basic chemicals from CO_2 (and water). This avenue is being explored by a team led by Beatriz Roldán Cuenya, who is Director of the Interface Science Department at the Fritz Haber Institute in Berlin, part of the Max Planck Society.

The researchers are especially interested in ethylene (also known as ethene) and ethanol. "Those substances are of great interest due to their high energy content, and because they are easy to store," explains Beatriz Roldán Cuenya. Furthermore, ethylene is the base substance for plastic polyethylene (PE), the most important plastic

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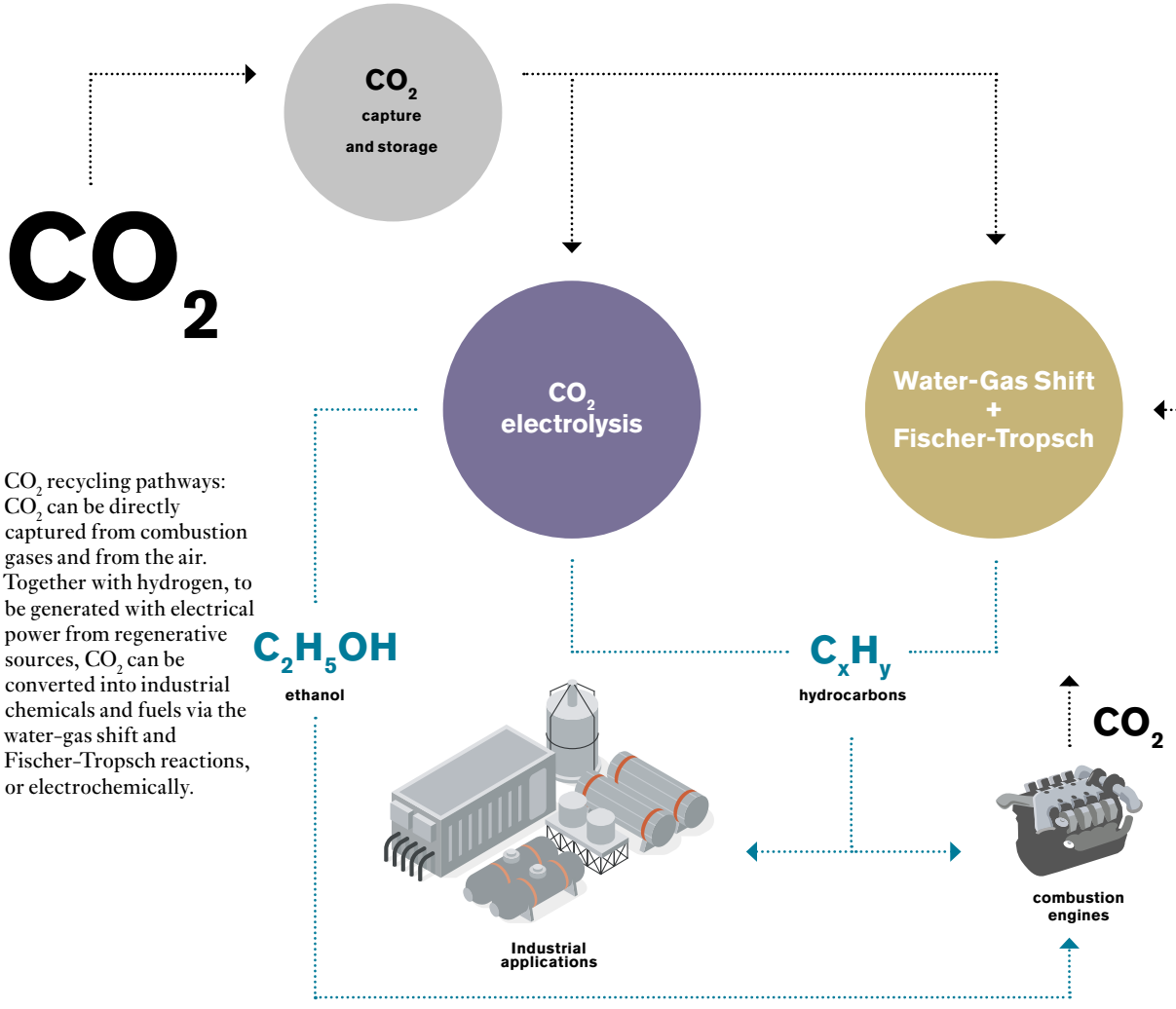


CO_2 recycling pathways: CO_2 can be directly captured from combustion gases and from the air. Together with hydrogen, to be generated with electrical power from regenerative sources, CO_2 can be converted into industrial chemicals and fuels via the water-gas shift and Fischer-Tropsch reactions, or electrochemically.

SUMMARY

Numerous research groups around the world are working on obtaining fuels or substances for chemical production from carbon dioxide.

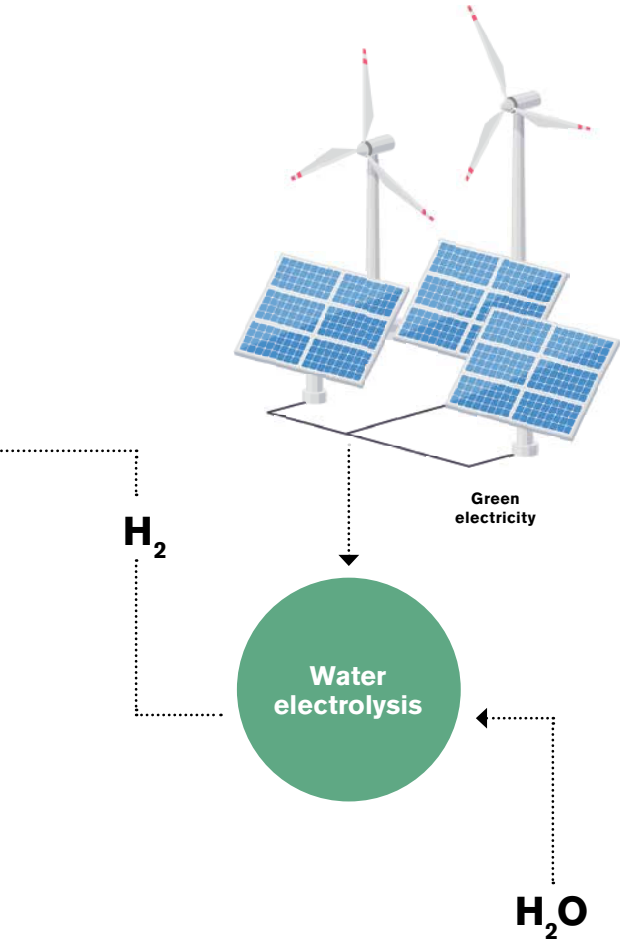
The team led by Beatriz Roldán Cuenya is trying to use electrolysis for the targeted production of fuels and industrial chemicals through high-yield processes.

Experiments have shown that the size, shape and chemical properties of the copper catalyst required make it possible to influence the reaction, so as to promote the creation of either ethylene or ethanol.

quantitatively speaking, and a key building block in many chemicals used in widely different industries. In the past, ethylene was produced exclusively from fossil raw materials. Ethanol, on the other hand, is suitable for use as a fuel due to its good combustibility, and it is already being added to premium petrol. For Roldán Cuenya, ethanol and ethylene are and will be "essential molecular building blocks of chemistry," even in the longer term. The physicist thus believes that fossil-free production of these substances from CO_2 and green hydrogen is a "high-priority goal in chemical energy conversion efforts."

From a scientific perspective, one of the primary tasks is to develop suitable catalysts for the production of ethylene and ethanol. This is what the Berlin-based researchers are doing for the electrolysis of CO_2 but also for the electrolysis of water, which is split into hydrogen and oxygen in the process. Roldán Cuenya's team is currently working on catalysts for splitting water molecules that can replace the costly use of iridium, which is commonly used for the oxygen evolution reaction. The objective: to make the entire electrolysis process, and hence hydrogen synthesis, more economical. Great hopes are pinned on green hydrogen as a possible replacement for fossil raw materials one day, for example, in the steel and chemical industries. Green ammonia could also be synthesized this way, thus functioning as a storage medium for (green) hydrogen, facilitating its transport in tankers and through pipelines. Additionally, ammonia is the primary raw material used in the production of artificial fertilizers.

GRAPHIC: GCO ACCORDING TO BEATRIZ ROLDAN / FHI, ISTOCK



Returning to CO_2 electrolysis, the good news is that it is already possible to obtain the two desired substances ethylene and ethanol from CO_2 through electrolysis. Clara Rettenmaier, a PhD student in Roldán Cuenya's department, showed us what this looks like on a small scale in a lab at the Fritz Haber Institute. She presented a cylindrical glass vessel containing a colorless liquid with gas bubbling through it. Inserted into the liquid is a kind of stylus, with a one cent coin attached to the bottom. "The stylus serves as the electrode; we apply voltage to it to reduce the CO_2 released into the water through the gas bubbles. The copper coin is our catalyst," explains the chemist. The coin makes the demonstration more striking for visitors. The actual catalysts used are much smaller – copper nanoparticles invisible to the human eye.

With a few clicks on a computer just next to the lab apparatus, the chemist calls up measurement curves that provide information about the products formed. "That's the ethylene there," says Clara Rettenmaier, pointing to a peak in a curve. Moving her finger on to further spikes, she continues: "And that's methane, this is carbon monoxide, and up here we have hydrogen."

In search of a process selection mechanism

The problem the research group is intensively working on can be described as a search for a process selection mechanism. "Theoretically, a whole range of compounds can be created from CO_2, but unfortunately, they often form at the same time," explains Roldán Cuenya. Another problem is that the applied voltage simultaneously also splits water into hydrogen and oxygen. Since product mixtures make further processing complicated and expensive, it is important to have an economically feasible process in which the single desired substance is obtained with maximum yield, as Roldán Cuenya further elaborates.

Thus, the question her research department is addressing is: how can electrolysis be controlled so as to maximize production of ethylene, or ethanol? Clearly, the right catalyst is required for this. The basic job of the catalyst is to break the bonds of CO_2 and stabilize certain intermediate products to enable new bonds to form. Roldán Cuenya's team is studying precisely what happens on the surface of the catalyst during the reaction process, namely, how the material reacts and adapts to the reaction conditions.

To date, copper has been the only known catalyst material that can electrochemically convert CO_2 into compounds with two or more carbon atoms. The necessary carbon-carbon coupling process in electrolysis occurs only with copper. This is apparently the case because the distances between the copper atoms in the copper metal lattice and the strength of the bonds between the copper and carbon atoms are optimal.

Unlike in the apparatus used for their demonstration, the actual experiments do not involve a copper coin but rather tiny little copper oxide cubes. The Berlin-based team produces these so-called "nanocubes" themselves – you would have to line up about a thousand of the cubes to equal the diameter of a hair. The tiny cube shape means the copper has a

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Depth at surface level: Lara Celeste Chaves, Rosa Maria Arán-Ais, Clara Rettenmaier, Antonia Herzog, and Beatriz Roldán Cuenya (from left) study ways of controlling the electrocatalytic conversion of CO_2.

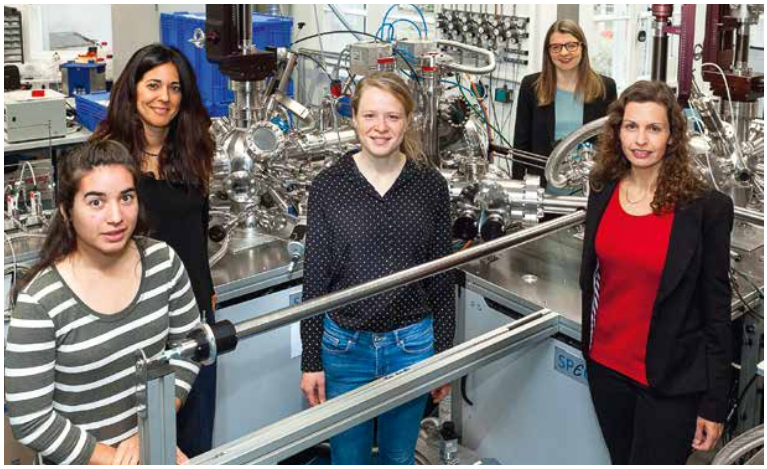


PHOTO: FHI / CHRISTIAN TESSMAR

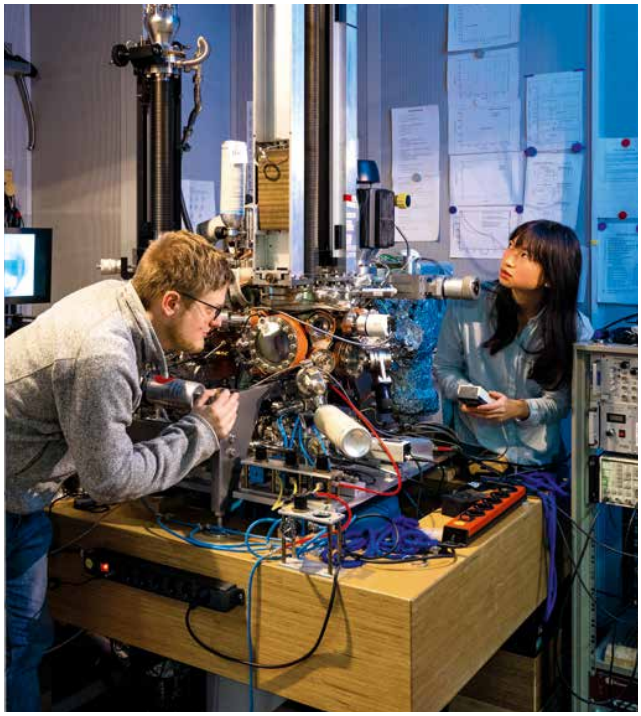


PHOTO: FHI / JÜRGEN LÖSEL

Nanoscopic surface exploration: Felix Landwehr and Claudia Khanh-Ly Nguyen adjust an atomic force microscope usable to create profiles of surfaces.

much larger surface area per gram than a cent coin, so with the same amount of copper, much more CO_2 can react. The researchers affix the catalyst cubes directly to the electrode, which is then immersed in CO_2-saturated water. In addition, the water's electrolytic properties have been improved using dissolved potassium salt.

The electrolytic cell will fit into a coffee cup, but the Berlin research group employs entire rooms full of equipment. This is because with some measurement methods, the smaller the structure that is to be studied, the more space is required. Ultimately, the researchers are interested in what happens to the catalyst at the atomic level during electrolysis, which means on the scale of a millionth of a millimeter. The department maintains a vast range of equipment to render this visible in complete chemical and physical detail, distributed over several large laboratories in multiple buildings. Roldán Cuenya and her team have modified certain methods, such as electron microscopy, to allow their use in the aqueous environment of electrolysis.

In some cases, multiple measurement technologies have to be combined for a single experiment. Doing so was necessary, for example, to reveal that the actual active centers of the catalyst material only form under reaction conditions, and that these constantly change during the process. Using liquid-phase electron microscopy, the team has now also made visible other changes in the catalyst that occur during CO_2 electrolysis. "We have observed that the catalyst cubes change their shape and size during the electrolysis process," explains Roldán Cuenya. Clearly, such morphological changes affect catalytic properties as well. Routine use of this process in an industrial setting would thus only be possible once it is known how to stabilize the active phases of these catalysts.

Another of the team's key findings is that the active centers of the catalyst for the undesired side reaction – in which hydrogen is split off from water – differ from the active centers for the electrocatalytic reduction of CO_2. Furthermore, the researchers have also discovered that there is apparently an ideal cube size. "If the cubes are too small, they simply detach and accumulate elsewhere," says Roldán Cuenya. This is disadvantageous, she notes, because such agglomerations mean a loss of catalytically active surface area.

However, the catalyst also changes chemically in the course of the reaction, as experiments using X-ray photoelectron spectroscopy have shown. The textbook rule that a catalyst does not change in the course of a reaction is thus not true in all cases. The pre-catalyst was initially in oxidized form owing to the production process, but gradually this was reduced until a certain proportion of elemental copper was reached. The problem: this steers the reaction in a different direction than the oxide.

Anti-aging cure for the catalyst

The scientists devised a clever idea for controlling the conversion to pure copper during the reaction: simply reversing the process after a certain period by applying a voltage with opposite polarity. That served to re-oxidize the metallic copper atoms, regenerating the catalyst to some extent. The group commenced experiments in which they applied voltage in pulses, switching between positive and negative polarities. As predicted, the procedure did indeed effectively reverse changes in the catalyst, prompting Roldán Cuenya to call this an "anti-aging" procedure. But regularly switching the voltage between positive and negative had another effect as well: it acted as a selectivity lever, because the duration of the respective pulses can be used to promote the formation of certain products. Long reduction pulses, for example, promote the production of ethylene, while long oxidation pulses produce more carbon monoxide. Furthermore, long reduction pulses of several seconds' duration combined with short oxidation pulses significantly increases ethanol yield.

The extensive analysis conducted by the team has now enabled good visual

rendering of precisely what happens. For example, the researchers observed that more ethanol is synthesized when thin, disordered copper oxide clusters form on the surface of elemental copper. Ethylene, in contrast, appears more likely to form on elemental copper than on oxidized copper. This provides a plausible explanation for why longer reduction pulses promote ethylene synthesis. The methods employed by the team at the Fritz Haber Institute in Berlin are also effective, among other things, for identifying the influence on electrolysis of defects or foreign metal atoms in the lattice of copper atoms. Thus, it emerged that ethanol synthesis is accelerated by adding five-percent silver.

A contribution to fighting climate change

These are all just initial insights into possible ways to achieve selectivity. "The main thing right now is to gain a better understanding of the mechanisms," emphasizes Roldán Cuenya, adding: "You just can't make a leap before you've learned how to walk." In other words, we still have a lot to learn before it will be possible to custom-design the optimal catalyst for a specific desired reaction and bring it into large-scale industrial usage.

Industrial applications may still be a long way off, but for the Max Planck Director Roldán Cuenya, conducting "fundamental research with social relevance" is important. She envisions that sometime in the future, electrochemical processes will be conducted with CO_2 right out of the air. Research is already underway at various institutions into the direct air capture technologies required for this. Roldán Cuenya believes that achieving a complete restructuring of the energy and chemicals industries around sustainability objectives will pose one of the greatest challenges society faces in the fight against climate change. And she hopes to contribute to these efforts with her work.

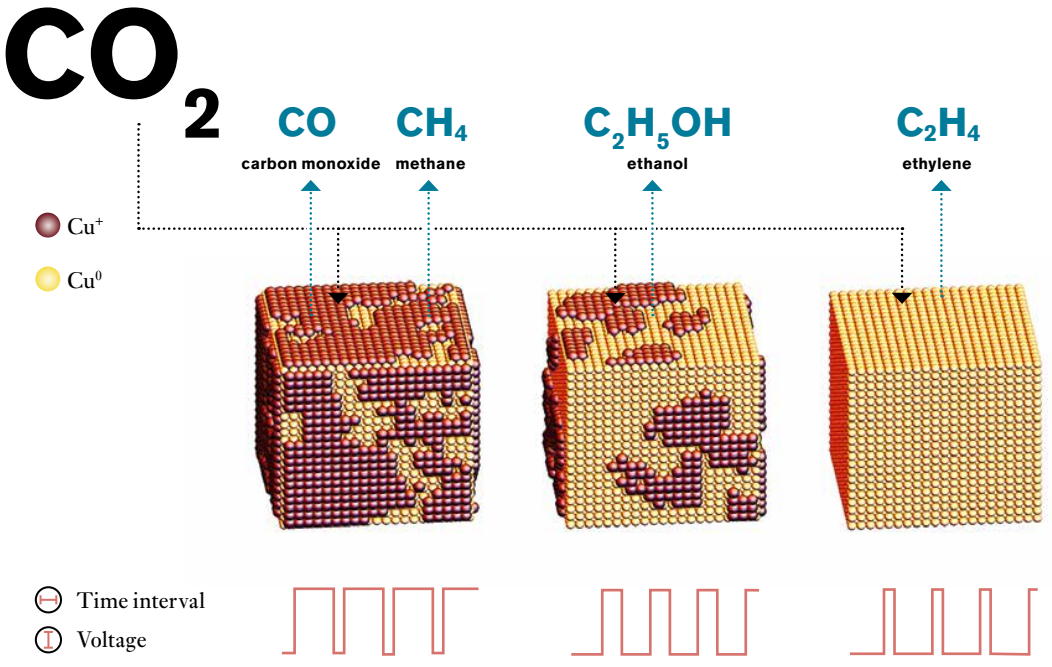
GLOSSARY

ELECTROLYSIS
An electric current between two electrodes in an electrolyte is used to chemically transform substances. One electrode (the anode) takes on electrons from a substance within the electrolyte, while the other (the cathode) gives up electrons to another substance.

LIQUID PHASE ELECTRON MICROSCOPY
Electron microscopy is a high-vacuum microscope that uses an electron beam to depict atomic structures. Beatriz Roldán Cuenya has found a method enabling the study of samples in liquids that under normal conditions would immediately evaporate.

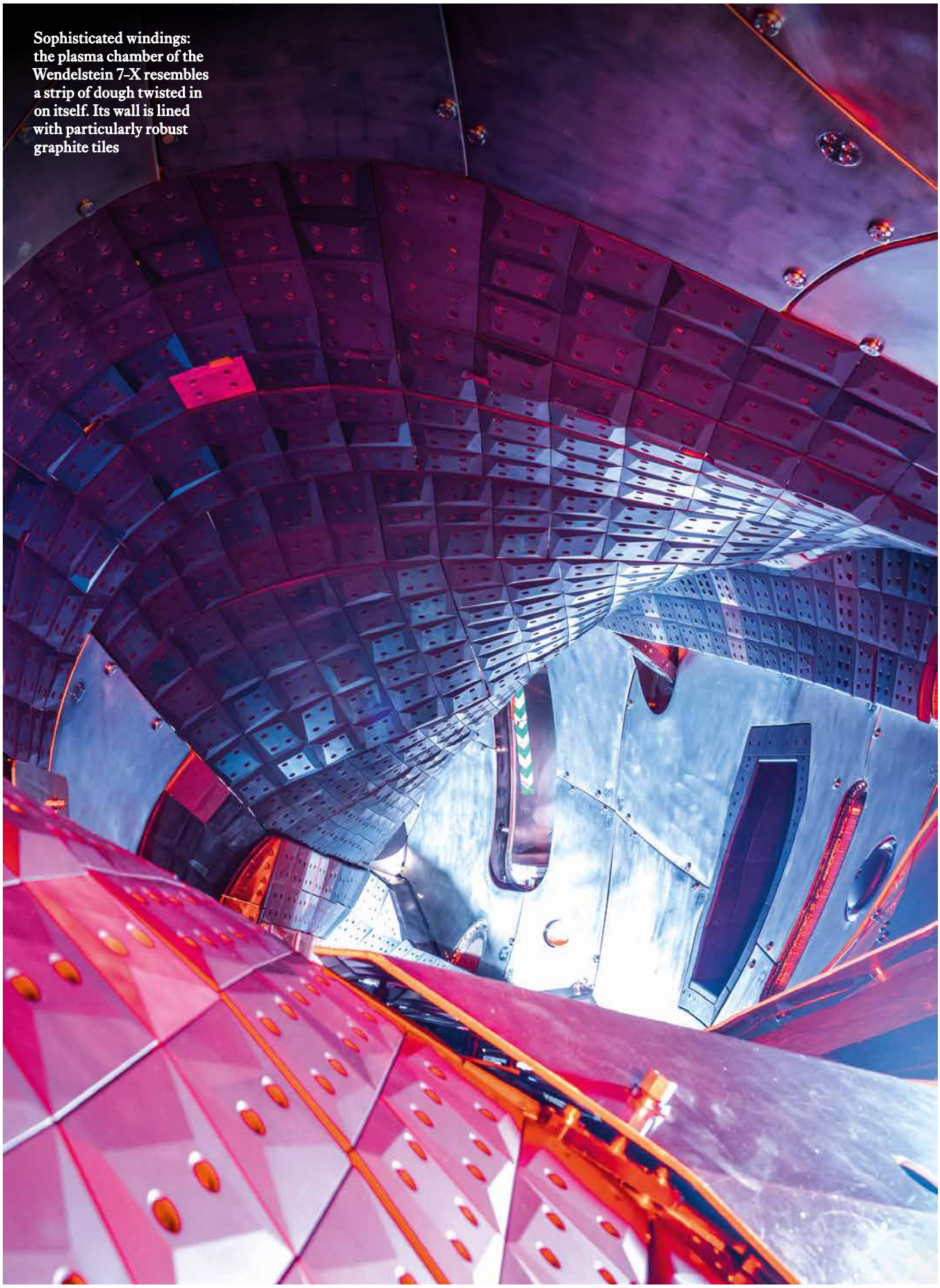
CATALYST
A substance that lowers the energetic hurdle for a reaction to occur, thereby enabling or facilitating the formation of certain products.

X-RAY PHOTOELECTRON SPECTROSCOPY
A technique in which an X-ray beam releases electrons from the surface of a sample; these electrons provide information about the chemical properties of the surface.



Controlled reaction: carbon monoxide and methane (left cube) are the primary products generated during electrolytic reduction of CO_2 on nanocubes with substantial copper oxide on their surface. The reaction proceeds in this direction if the polarity of the reducing voltage is regularly reversed over an extended period of time (left square graph), so that the surface is oxidized. Less oxide forms on the surface if the oxidation pulses are shorter, in which case ethanol is the main product (center cube). Long reduction pulses keep the surface free of oxides, resulting in CO_2 being reduced to ethylene (right cube).

CHART: GCO ACCORDING TO TIMOSHENKO, J., BERGMANN, A., RETTENMAIER, C., ET AL. STEERING THE STRUCTURE AND SELECTIVITY OF CO_2 ELECTRO REDUCTION CATALYSTS BY POTENTIAL PULSES. NAT CATAL 5, 259–267 (2022)



Sophisticated windings: the plasma chamber of the Wendelstein 7-X resembles a strip of dough twisted in on itself. Its wall is lined with particularly robust graphite tiles

PHOTO: JAN HOSAN / MPI FOR PLASMA PHYSICS

FOCAL POINTS IN NUCLEAR FUSION

TEXT: ANDREAS MERIAN

The National Ignition Facility in the USA announced a breakthrough in fusion research in December 2022. Nuclear fusion offers the promise of a clean and practically inexhaustible source of energy. The Max Planck Institute for Plasma Physics is also working on ways to harness this. The institute's scientific director, Sibylle Günter, and director emeritus, Karl Lackner, share insights into where some of the public and private fusion projects stand – and how they compare to the concepts their institute is researching.

A glass of seawater contains as much energy as a barrel of oil. But unlike the more than 300 kilograms of CO_2 released when 159 lIters of oil are burned, no greenhouse gases are produced when energy is extracted from water. However, in order to be able to access this energy at all, we must first master nuclear fusion. It offers the enormous promise of practically unlimited energy, and clean energy at that – which is to say: it also wouldn't produce long-lived radioactive waste. Nuclear fusion would be an ideal addition to renewable energy sources in seasons and areas with little wind and sun.

Fusion energy is produced when light nuclei fuse together. This, however, only occurs naturally under conditions such as those found in the sun. Scientists and engineers alike have been trying to achieve the technical prerequisites for decades. But because fusion research is still a long way off from being used in an energy-producing power plant, some people sarcastically refer to it as the "fusion constant": generating electricity from a fusion reactor is always thirty or even fifty years in the future.

Iter is currently the largest and most expensive fusion project in the world, with a current estimated cost of 18 to 22 billion euros. The name stands for International Thermonuclear Experimental Reactor and is a research project undertaken by the EU, USA, China, India, South Korea, Japan, and Russia. The Max Planck Institute for Plasma Physics is also involved. Iter is expected to release about ten times as much fusion energy as goes into starting the fusion reaction. But Iter will not generate electricity. This will first happen in a demonstration power plant, which is being planned under the simple name of Demo and is intended to test the interactions between all of the power plant's components. It will be built as soon as the Iter experiments are complete. That, however, may be a while yet.

Iter was originally scheduled to begin operations back in 2016. It was then said that the reactor would be up and running in 2025 and able to produce fusion power in 2035. But it was recently announced that even this timeline would not be met. "Iter is not a purely scientific project; it also has a political component," says Sibylle Günter, Director at the Max Planck Institute for Plasma Physics in Garching. Political constraints also create technical difficulties. This is because the partner countries not only share the financing, but also the development and production. "This means

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that the individual components of the reactor are manufactured in the different countries, which results in some things not fitting together as planned," says Sibylle Günter. Iter's press release also mentioned "extensive repairs".

Meanwhile, many private enterprises have also started working on nuclear fusion despite, or perhaps because of, the painstaking progress of this large-scale, government-funded project. After all, the prospect of unlimited clean energy is incredibly exciting. According to the Fusion Industry Association, 33 companies around the world are trying to achieve just that. Some of them are pursuing fundamentally different technical approaches to nuclear fusion and are promising both their investors and the general public that fusion energy will soon be commercially viable. The companies have raised more than $4.7 billion in investments to date to achieve this goal. Although start-ups are certainly more agile than government projects such as Iter, they are often on much shakier ground in terms of scientific and technical feasibility. "The current mainstream research approaches are compromises," says Karl Lackner. The director emeritus at the Max Planck Institute for Plasma Physics in Garching spent decades researching nuclear fusion and experienced both progress and unexpected obstacles in the process – the same process on which Iter is based. "A reactor like Iter presents a solution to all the problems we've identified so far – it's not the optimal solution for any of them, but it's at least a sufficient solution for all of them. A few of the alternative approaches do an excellent job of solving one problem and are, therefore, exciting. But the other problems are proving more difficult or may even be impossible to solve."

All of the approaches have one thing in common: they are modeled after the process by which the sun generates energy. In it, the nuclei of hydrogen atoms fuse to form helium at a pressure of around 200 billion bar and a sweltering 15 million degrees Celsius. Under these conditions, matter exists as plasma, meaning that electrons and positively charged atomic nuclei are no longer bound to each other. The high temperature provides the positively charged nuclei with the necessary speed to overcome the electrostatic repulsive force between them. The pressure inside the sun also compresses matter to the point that it becomes more likely that two nuclei will collide. It is not technically feasible to achieve this pressure on Earth, which is why much higher temperatures are required in fusion reactors to trigger the fusion of nuclei. Ordinary hydrogen atoms also fuse much too slowly for technical use. However, a technically feasible solution was found in physics more than seventy years ago: the fusion of heavy and superheavy hydrogen – also known as deuterium and tritium. The Max Planck Institute for Plasma Physics is investigating two of the oldest concepts for a fusion reactor. Researchers at the Garching site are experimenting with the Asdex Upgrade, which, like Iter, is a tokamak. A tokamak is a donut-shaped vessel within which a strong plasma current is used to confine the electrically charged plasma particles. By contrast, the Greifswald site is working on the Wendelstein 7-X reactor, a stellarator. The stellarator also constrains the plasma in a ring-shaped vessel using a magnetic field, which is, however, produced purely by currents in external conductors. In this case, however, his plasma vessel and magnetic field resemble a strip of dough twisted in on itself several times rather than a smooth doughnut.

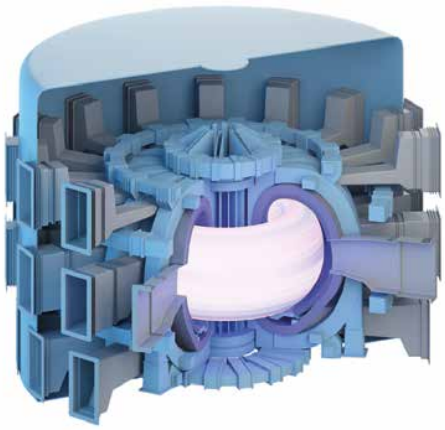
The first task for both types of reactors is to trap the hydrogen plasma with the magnetic field in such a way that the charged particles do not touch the wall if possible. If the plasma makes too much contact with the vessel, it will cool down too much and make a self-sustaining fusion reaction impossible. Although the geometry of the magnetic field in the tokamak is simpler than in the stellarator, a current must flow through the plasma ring in the tokamak, which introduces some practical problems for efficient power plant operation. These problems do not appear in a stellarator. "Conceptually, the stellarator is better suited for a fusion power plant," Günter explains. "However, a stellarator's magnetic field has to be optimized, which is only possible with sufficient knowledge of physics and computing power. This is why fusion research initially took the simpler approach of the tokamak." Demo is currently also planned as a tokamak. If, however, the stellarator concept proves to be superior by the time construction begins, these plans could still be overturned. The fact that both the stellarator and the tokamak are being researched at the Max Planck Institute for Plasma Physics is unique for any research facility worldwide. This enables a level of objectivity that is important in ba-

SUMMARY

Nuclear fusion has the potential to provide practically unlimited clean energy and is, therefore, being researched in some large-scale government research projects such as Iter, Asdex Upgrade, and Wendelstein 7-X, as well as many start-up companies.

The intention is for Iter to deliver more energy than goes directly into triggering nuclear fusion, but it keeps getting delayed. To operate, however, Iter also requires more energy than nuclear fusion generates and it does not produce electricity. The Demo power plant is intended to do just that.

Some of the private initiatives have announced very ambitious timelines, which should be viewed skeptically. These often provide a very good solution for one problem posed by nuclear fusion, but do not adequately address others.

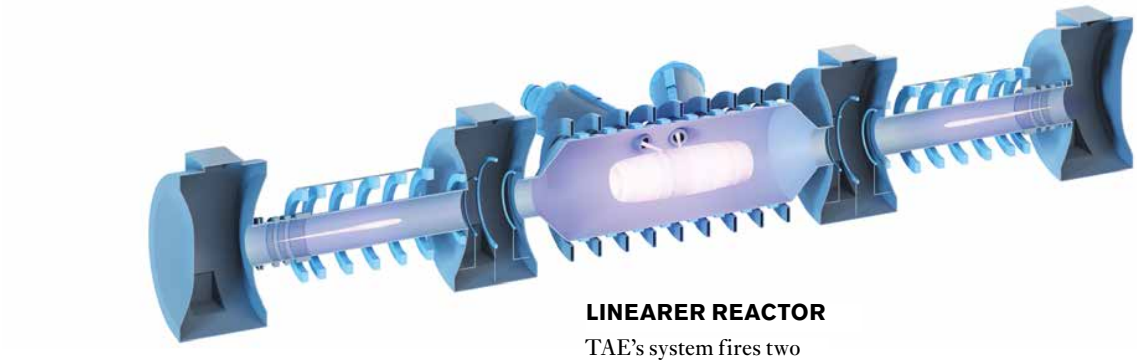


TOKAMAK

The Asdex Upgrade, Iter, and potentially Demo have plasma chambers that are shaped like a doughnut.

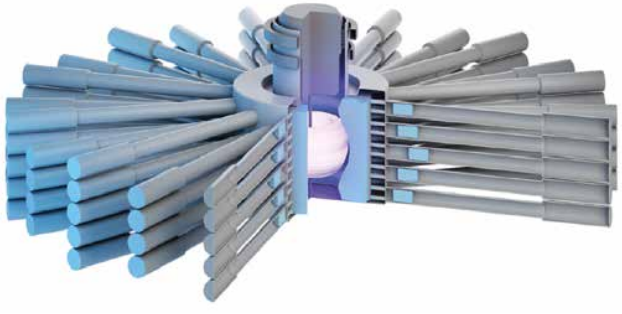
STELLARATOR

A winding magnetic field encloses the plasma in the plasma chamber, which is shaped in the same way, for instance in the Wendelstein 7-X.



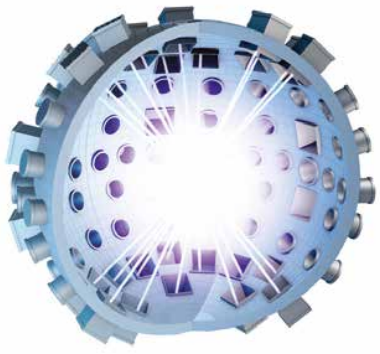
LINEARER REACTOR

TAE's system fires two plasma packages at each other, producing rotating cylindrical plasma.



MODIFIED TOKAMAK

General Fusion generates plasma in a container of rotating liquid metal that is compressed with pistons to ignite it.



INERTIAL CONFINEMENT FUSION

The NIF and some start-up companies are exploiting the inertia of mass that holds the plasma together after it has been compressed and heated with powerful lasers.

ILLUSTRATION: P. BALL, THE RACE TO FUSION ENERGY, NATURE, VOLUME 599 ISSUE 7886, 25 NOVEMBER 2021; TRAGEHEITSFUSON: GCO

sic research, says Sibylle Günter: "We are not locked in and can compare and openly discuss the pros and cons. In addition, the research conducted on both types of facilities benefits the other."

Small tokamak with powerful magnets

In order to reach the necessary temperature for fusion in both types of reactors, the hydrogen plasma is heated by firing in fast hydrogen atoms, using electromagnetic radiation, and, in the case of the tokamak, also by the resistance of the plasma current. Once the conditions are finally right, the nuclei of deuterium and tritium fuse, and a helium nucleus and a neutron are created, both with considerable kinetic energy. The magnetic cage is permeable to uncharged neutrons, allowing the particle to penetrate the vessel wall with full energy. The resulting heat is to be used to generate electricity in the same way as in a conventional power plant. The material in the wall, however, remains as slightly radioactive waste.

Commonwealth Fusion Systems is also among the startups focusing on the tokamak design. The company even announced that its prototype Sparc should be operational in as little as five years. They are aiming to achieve this with a tokamak that is much smaller than Iter and which can be modified more quickly and cost-effectively to produce a reactor that is ready for the market. In order to confine the plasma in it, much stronger magnetic fields are required. Consequently, at the core of Sparc are novel magnetic coils made of high-temperature superconductors that are more powerful than Iter's superconducting coils and require less cooling. Research into this technology was conducted for a long time at MIT in Cambridge, Massachusetts, giving rise to the start-up. "I'm happy that Commonwealth Fusion Systems is continuing to explore the high-field approach," says Karl Lackner. "There is a good chance of success, since the basic principle has been tried and tested for a long time. Having said that, experience has taught us to be skeptical when it comes to announced timelines." Nevertheless, Commonwealth Fusion Systems was able to convince private investors of its idea: the startup raised more than $1.8 billion last year.

The merger start-up TAE Technologies also has strong support from Google, and not just financially. Google is also helping by providing computing power and expertise in the field of artificial intelligence. "TAE is taking an old approach that has only regained traction with the use of advanced feedback techniques," explains Karl Lackner. TAE combines particle accelerators and magnetic coils to create a plasma cylinder that is roughly the shape of a tin can without a lid or bottom. The cylinder rotates like a roller, which stabilizes it – but only temporarily. Without additional measures, its rotation would gradually slow down and the plasma cylinder would eventually collapse. It was only through extensive calculations with the support of Google that TAE was able to get an understanding of the instabilities and control them through feedback loops. Karl Lackner is impressed by this progress, but he is also critical: "TAE is currently at the same stage as research on tokamaks in the 1970s and 1980s in terms of the triple product, i.e., the combination of temperature, particle density, and confinement time, but most importantly, it still has a particle density that is far too low." The triple product is a measure of how close the plasma comes to the conditions for self-sustaining nuclear fusion. In 2019, TAE had not yet reached the value achieved by the predecessor of Asdex Upgrade at the Max Planck Institute for Plasma Physics in 1989. Moreover, like a few other companies, TAE is not pursuing the fusion of tritium and deuterium, but of boron and protons. This would eliminate the need for tritium, which is radioactive and difficult to obtain, and would not result in a radioactive reactor wall. "It is, however, much more difficult to fuse boron and proton, and the yield is also lower," says Karl Lackner.

While TAE's progress was based on theoretical calculations, General Fusion's breakthrough is expected to come from innovative engineering. In both the conventional tokamak and the stellarator, the interaction between the reactor wall and the plasma presents a problem. Consequently, fusion research has been searching intensively for years for the right materials for the reactor wall. General Fusion is taking a different approach

Typical large construction site: the Iter fusion reactor is being built at the Cadarache research center in France – but there have been repeated delays. The plasma chamber will run through the loop-shaped elements when it is finished.

from mainstream research here: they are attempting to enclose the plasma with liquid metal. The metal will not be destroyed by the interaction with the plasma and therefore, does not need to be repeatedly replaced. Moreover, the wall of liquid metal facilitates the dissipation of fusion energy in the form of heat. General Fusion is employing a modified tokamak design for the reactor. To do this, the liquid metal is made to rotate in the reactor. It is pressed against the wall of the vessel in the same way as laundry during a spin cycle, creating a cavity in the center. The deuterium and tritium plasma will be introduced into this cavity. However, in order to ignite the plasma, i.e., to start nuclear fusion, it needs to be further compressed. In order to accomplish this, General Fusion plans to use precisely controlled pistons mounted all around the reactor wall to compress the liquid metal and its plasma core. But Lackner also believes that this is one of its biggest challenges: "The compressed plasma is likely to be unstable." Despite this, General Fusion announced that it will be building a demonstration power plant in Culham, England, in partnership with the United Kingdom Atomic Energy Authority. This is expected to be completed in 2025, paving the way for the first commercial fusion power plants in the late 2020s or early 2030s.

What all the projects mentioned so far have in common is that they use a magnetic field to enclose the plasma. The National Ignition Facility (NIF) in the USA and the German start-ups Marvel Fusion and Focused Energy are pursuing a completely different path. They are focusing on laser-based inertial confinement fusion. In this process, the conditions required for nuclear fusion can only be achieved for a very short time, usually for a few nanoseconds. The plasma is

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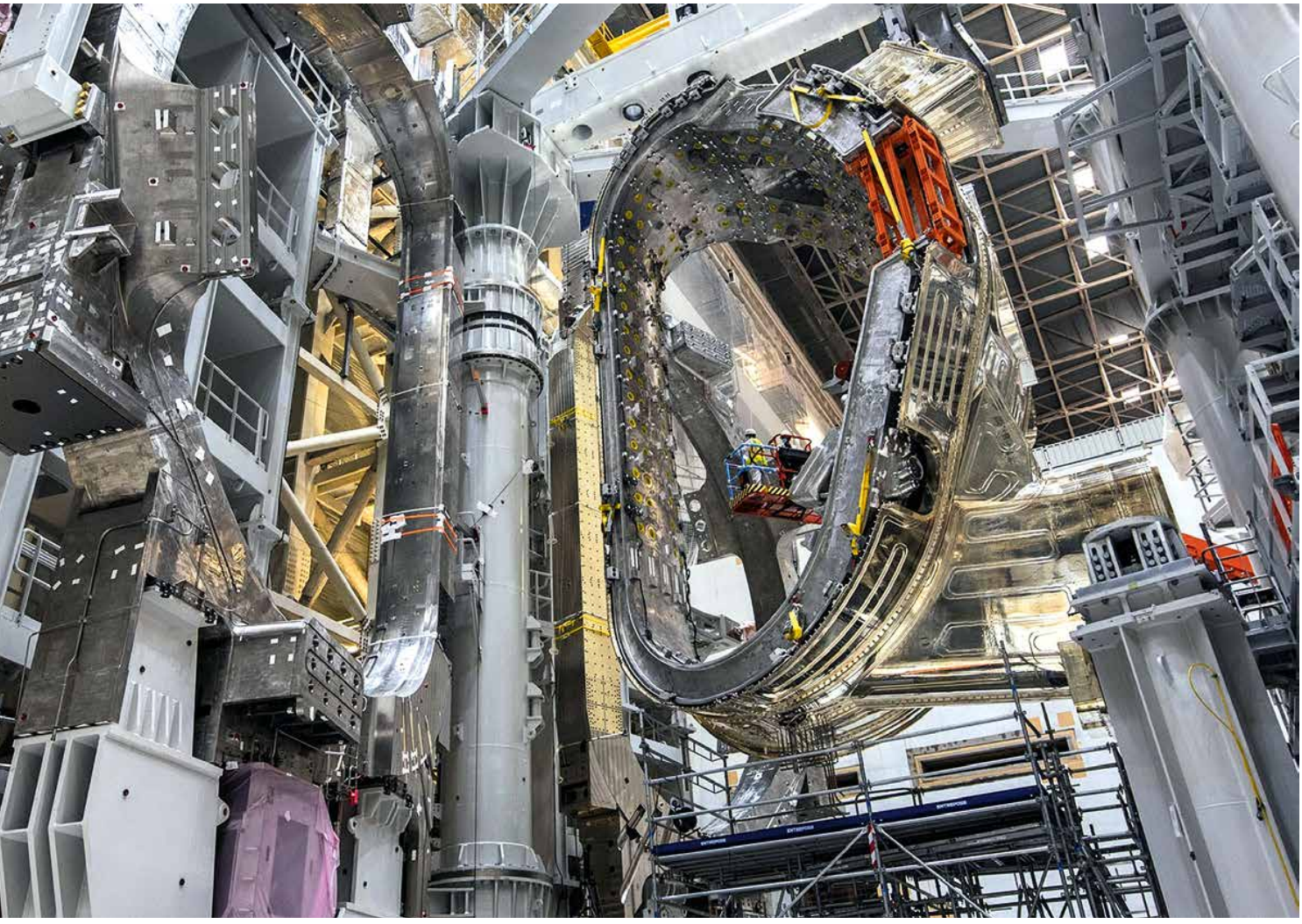
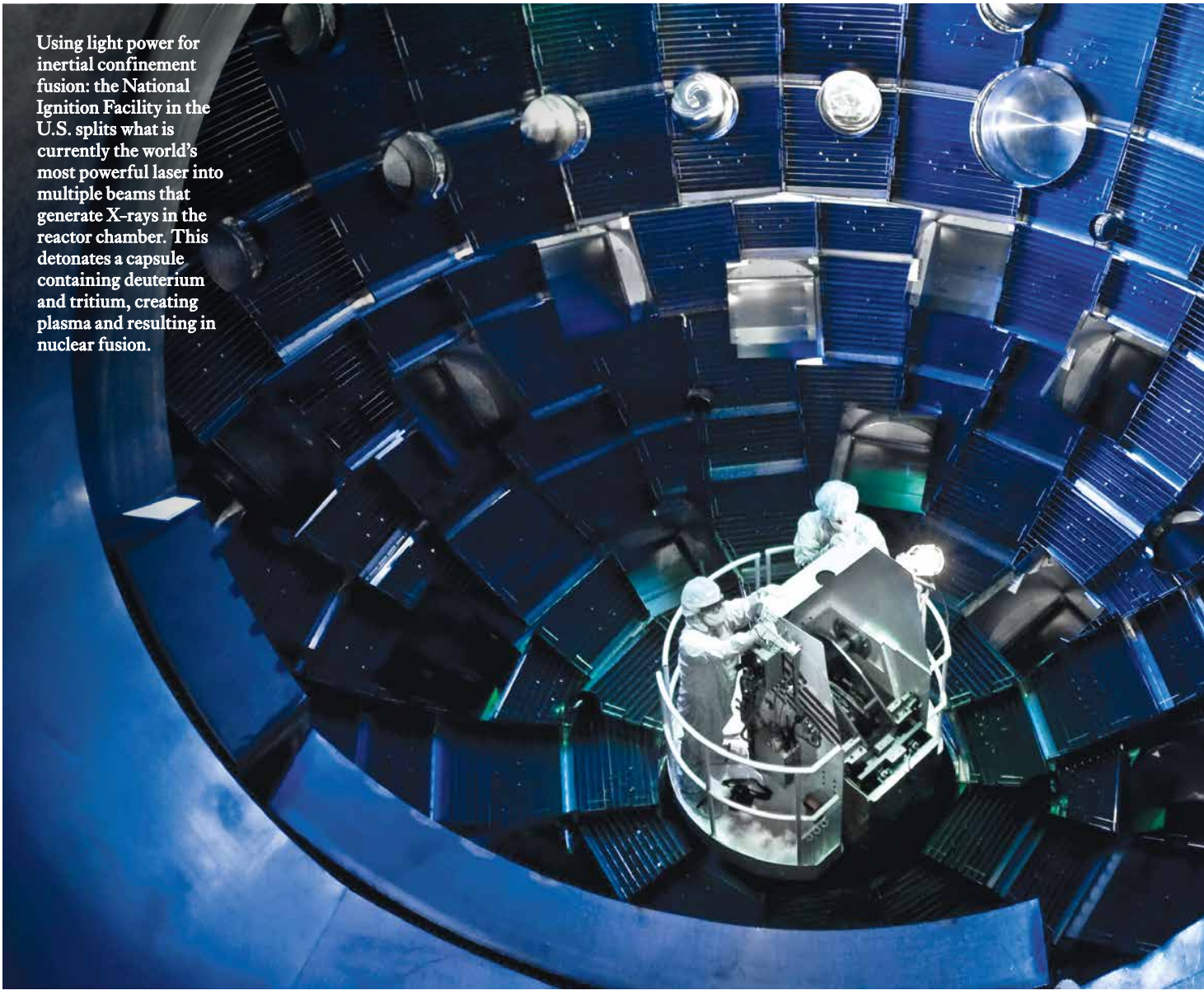


PHOTO: ITER ORGANIZATION, HTTP://WWW.ITER.ORG/



Using light power for inertial confinement fusion: the National Ignition Facility in the U.S. splits what is currently the world's most powerful laser into multiple beams that generate X-rays in the reactor chamber. This detonates a capsule containing deuterium and tritium, creating plasma and resulting in nuclear fusion.

held together for this short time purely due to its inertia and does not have to be elaborately confined in a magnetic cage. High-powered lasers are used by the researchers to achieve the high temperature and density required for nuclear fusion within a very short time. The NIF at Lawrence Livermore National Laboratory is primarily a military research facility, since laser-based inertial confinement fusion can be used to study what happens when a hydrogen bomb is detonated. Despite this – or perhaps because of it – this facility is the most advanced system around for inertial confinement fusion. NIF uses what is currently the most powerful laser in the world. It produces the temperature and density required for fusion indirectly via multiple intermediate steps, with the laser heating the inner wall of a cavity to a temperature making it an effective radiator of X-rays. In December 2022, NIF researchers made a record-breaking shot: the nuclear fusion process released about 50 percent more energy than was input by the laser to create and ignite the plasma. The team has, however, only been able to reproduce similar successes with difficulty, since even the smallest deviations in the geometry of the experiment, among other things, can lead to large differences in the results. In any case, this approach is far from being implemented in a power plant: at present, the NIF facility can only fire four to six shots per day; a power plant would need to fire several per second.

Unlike NIF, the two German startups are aiming ultra-short laser pulses directly at a capsule containing the fuel. Focused Energy, a spin-off of the Technical University of Darmstadt, wants to first generate and compress

PHOTO: LAWRENCE LIVERMORE NATIONAL LABORATORY

the plasma by bombarding a pellet filled with deuterium and tritium with a laser beam. A second, more powerful, but shorter pulse laser should then produce fast ions heating the plasma to ignition. This two-stage approach reduces the total laser energy required, thereby saving costs. "It's an exciting approach – if it works," says Sibylle Günter. "And I'm skeptical of the timeline." After all, the first power plants are expected to produce electricity in the mid-2030s – a plan that even the company itself calls challenging. Marvel Fusion's laser-assisted inertial confinement fusion technology has a trick to it: the capsules containing the fuel have a special nanostructure. Only a few scientific details of the approach are public, however, and Günter and Lackner are accordingly skeptical. "Based on the publicly available information, it is not clear how Marvel Fusion's approach is supposed to work," Lackner states.

The overall energy balance causes problems

One problem is thwarting all of the approaches currently being pursued: so far, fusion reactors are nowhere near being able to produce more energy than is needed for their entire operation. When it comes to the use of nuclear fusion in power plants, it is ultimately not the energy balance of the fusion reaction that is decisive, but the net energy yield of the entire power plant. Even Iter will not be in the black. Although, it should generate more energy than flows directly into the plasma, Iter, as a power plant, would still consume more energy in total than it generates. This is because an enormous amount of energy is required to cool the large magnetic coils and to heat the plasma. Moreover, the heat generated by nuclear fusion cannot be converted into electricity without efficiency losses. In theory, Iter could cover about half of its own energy needs. With inertial confinement fusion, the difference is even greater: in the most recent and best-performing experiment to date on laser-based inertial confinement fusion at NIF, 150 percent of the energy from the laser was recovered through nuclear fusion. But generating the laser energy required about 150 times more energy than arrived in the reactor chamber. As such, the fusion reaction released only about one percent of the energy used as heat. At best, about 50 percent of this could be converted into electricity. However, the demonstration pilot power plant Demo aims to prove that nuclear fusion by magnetic confinement, at least, is capable of producing true excess energy, as long as the plant is large enough. But even if research groups someday manage to produce a self-sustaining fusion reaction with a positive energy balance, it remains to be seen whether this type of power generation will be economical.

Despite all the difficulties, fusion power remains a worthy goal. After all, the problems associated with fossil fuels are well known, and whether renewable sources such as wind and solar power will actually be able to meet humanity's growing energy needs is still uncertain. Which of the many approaches to nuclear fusion will ultimately be successful is difficult to predict. What is clear, however, is that competition should not stifle scientific exchange: "Whether it is government-funded research or a private-sector initiative, it is important that the results are openly communicated," says Karl Lackner. "This way, we will definitely be able to achieve our goal more quickly."

GLOSSARY

NUCLEAR FUSION
is the fusion of atomic nuclei. When these are light nuclei such as protons, energy is released in the process; this is how stars generate energy.

MAGNETIC CONFINEMENT
is the name of an approach to nuclear fusion in which plasma is confined in a magnetic field. This is mainly carried out in tokamak and stellarator systems, which differ in terms of how the magnetic field is generated.

INERTIAL CONFINEMENT FUSION
takes its name from the way the fusion plasma retains the necessary density for a short time due to the inertia of mass. Lasers can generate, compress, and heat the plasma.

PHOTO: ELSPETH READY

The village of Kangiqsujuaq, with its 800 inhabitants, lies in the far north of Quebec. For the Inuit who live there, hunting and sharing food are still important today.

Max Planck researchers cooperate with partners in more than 120 countries. In these articles, they talk about their personal experiences and impressions. Elspeth Ready from the Max Planck Institute for Evolutionary Anthropology in Leipzig regularly travels to the Canadian Arctic for research. She tells of magnificent expanses, special culinary delights, and an icy dog sled ride.

The village of Kangiqsujuaq has 800 inhabitants and is located in Nunavik, in the far north of Quebec. To get there, you take a flight from Montreal to Kuujjuaq, where you change to a smaller plane, filled with passengers and cargo, that stops at several towns along the Hudson Strait coast. The trip from Kuujjuaq usually takes half a day, but it's important to be patient and keep your plans flexible because flights are often delayed due to bad weather, sometimes for several days.

I first visited Kangiqsujuaq in 2011 with a team of archaeologists. We worked on documenting semi-subterranean houses just a few kilometers away from the modern village. The houses were occupied for hundreds of years by both Inuit and Tuniit, a population who lived in the region before Inuit arrived. After that first summer, I kept returning to Kangiqsujuaq and, motivated by my experiences and conversations with hunters, developed a research project focused on the role of hunting and food sharing in food security in Inuit communities.

Over the past century, Inuit have experienced extreme changes in their way of life. Many elders were born in igloos or tents and lived on the land until they were told by government officials to move to the village in the 1960s. Today, Inuit live in permanent houses and buy food and materials in shops, but the local language and cultural practices like hunting and food sharing are still strong. Nevertheless, the changes have not been easy. One of my current research projects, in collaboration with the local community council, focuses on experiences of stress and stress management strategies in the community.

During my last stay in Kangiqsujuaq, I lived in a small teacher's apartment that was free during the school holidays. In the morning, I usually write field notes and then conduct interviews in the afternoons. In the evenings, I often go visiting at the homes of my Inuit friends. Visitors are sometimes invited to eat, and a variety of local foods—like caribou, seal, beluga whales, geese, and grouse—might be served. My personal favorite is Arctic char. It tastes a lot like salmon, but much better! I especially like it dried with Montreal steak seasoning.

POST FROM

KANGIQSUJUAQ, CANADA

Traditional foods are an important source of nutrients and vitamins for Inuit today. Fresh foods are rare at the supermarkets in Kangiqsujuaq. Rice, pasta, and other nonperishable goods are delivered by cargo ship during the summer. Some fresh fruits and vegetables arrive weekly by plane, but are very expensive and soon out of stock. Traditional foods are also widely shared, and this sharing brings families and the wider community closer together.

Because much of my research focuses on traditional foods, I try to go along on hunting and fishing trips whenever I get the chance, so I can learn about what local food production involves. I can drive a snowmobile and I try to be helpful wherever I can – for instance, lending a hand in butchering a whale.

Being out on the land in the Arctic is an uplifting feeling for me. The landscape is vast, and the sense of freedom is indescribable. In Germany I am often asked how I cope with the darkness of the Arctic winter, but I grew up in Canada, so as a child, I was used to going to school and coming home in the dark. In fact, I often find the German winter much more oppressive: everything is gray and the sky is full of clouds. In the Arctic, the sky is usually clear, and you can see the moon and the stars, and the snow makes everything bright.

Once, I had the opportunity to go on a dog sled trip with friends who were training for an annual sled race. For seven hours we travelled across the snowy tundra and sea ice to a small cabin where we spent the night, then back again the next day. During the several hours of sledding at minus 25 degrees Celsius, I got frostbite on my nose, but my Inuit companions noticed it quickly before it got too bad. Fortunately, it has healed well!

PHOTO: PRIVATE

Elspeth Ready

36 is Canadian and studied anthropology at the University of Alberta and Trent University. After completing her Ph. D. at Stanford University, she moved to the Max Planck Institute for Evolutionary Anthropology in Leipzig at the beginning of 2019. Together with her team, she studies how traditional foods support food security, well-being, and resilience to climate change in Inuit communities.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

FIVE QUESTIONS

ON NEW DIGITAL COMPETENCES

FOR ANASTASIA KOZYREVA

Researchers from Berlin, Stanford, and Bristol have identified "critical ignoring" as a new way for people to gain more control over their use of online media.

Ms. Kozyreva, you were part of the team. Why do we spend so much time reading things online in the first place?

ANASTASIA KOZYREVA For us humans, it has always been very important to get information from our community and share it with others to survive. Negative or very emotional news grabs our attention, in particular, because it prepares us to avoid possible dangers, for example. This has served us well for millennia. But for a few years now, online media have been virtually flooding us with information. They are designed so that we spend as much time as possible on them, which means providers can place as much advertising as possible. We have not had time to adapt to this, which is why we need new digital competences. My colleagues and I consider critical ignoring to be just as important as critical thinking in dealing with online media.

How does critical ignoring work?

You can use three strategies here. The first one is *self-nudging*, which means that I design my environment in such a way that I can control what I really engage with. We can and we should actively decide how much time we spend on our smartphones, tablets, or PCs, and you can do this by setting up time limits on the devices, for example, or enabling do not disturb mode at night. This frees up time for offline activities that bring value to one's life – such as time spent with family and friends.

When I am online, though, quite a lot of news reaches me. How can I find out which bits are fake news?

There is a strategy for this, too, called *lateral reading*, i.e. reading sideways. In school we learned to critically examine a text by going through it very carefully from beginning to end. Fact checkers proceed differently: they open another tab in the browser – i.e., sideways – and do internet searches on who's behind the website. There is an astonishing number of sites that appear to be quite legitimate but in fact display inaccurate information (e.g., climate change denial), for example, in the interest of certain lobby groups, who try to influence public opinion in this way. We should always be suspicious of sources that we can't identify – whether they are websites, videos, or forwarded posts. With *lateral reading*, it often takes just a few minutes or even seconds to find out whether information is trustworthy.

A big problem in chats or on social media is hate speech. Should I respond when I read insults or racist and sexist comments?

No, absolutely not! Because that's exactly what these people want to achieve in spreading that kind of thing: they aim to provoke, and they feel vindicated when they get a response. The point here is to protect ourselves: engaging in discussions with online trolls and cyberbullies can be really damaging for our mental health and our relationships with other people. It's better to ignore the provocateurs, to block them, and in order to prevent them from damaging others, to report abusers to the platform operators.

Who did you develop your recommendations for?

This really concerns all of us, young and old alike. But I think it is particularly important to teach these strategies in schools. They are easy to learn and very effective. By teaching young people critical ignoring, you empower them to allocate their attention to online content consciously and intentionally.

Interview: Mechthild Zimmermann

Anastasia Kozyreva works at the Max Planck Institute for Human Development in the research area of Adaptive Rationality.

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- Luxembourg

PUBLISHER'S INFORMATION

MaxPlanckResearch is published by the Science and Corporate Communication Office of the Max Planck Society for the Advancement of Science. Legal headquarters of the association: Berlin.
ISSN 1616-4172

Publisher's mailing address
Hofgartenstraße 8
D - 80539 Munich
Tel: +49 89 2108-1719 / -1276 (before midday)
e-mail: mpf@gv.mpg.de
www.mpg.de/mpresearch
App for free download: www.mpg.de/mpr-mobile

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To improve readability, we have used only the masculine form in some of the texts. However, the chosen formulations address all genders equally.

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