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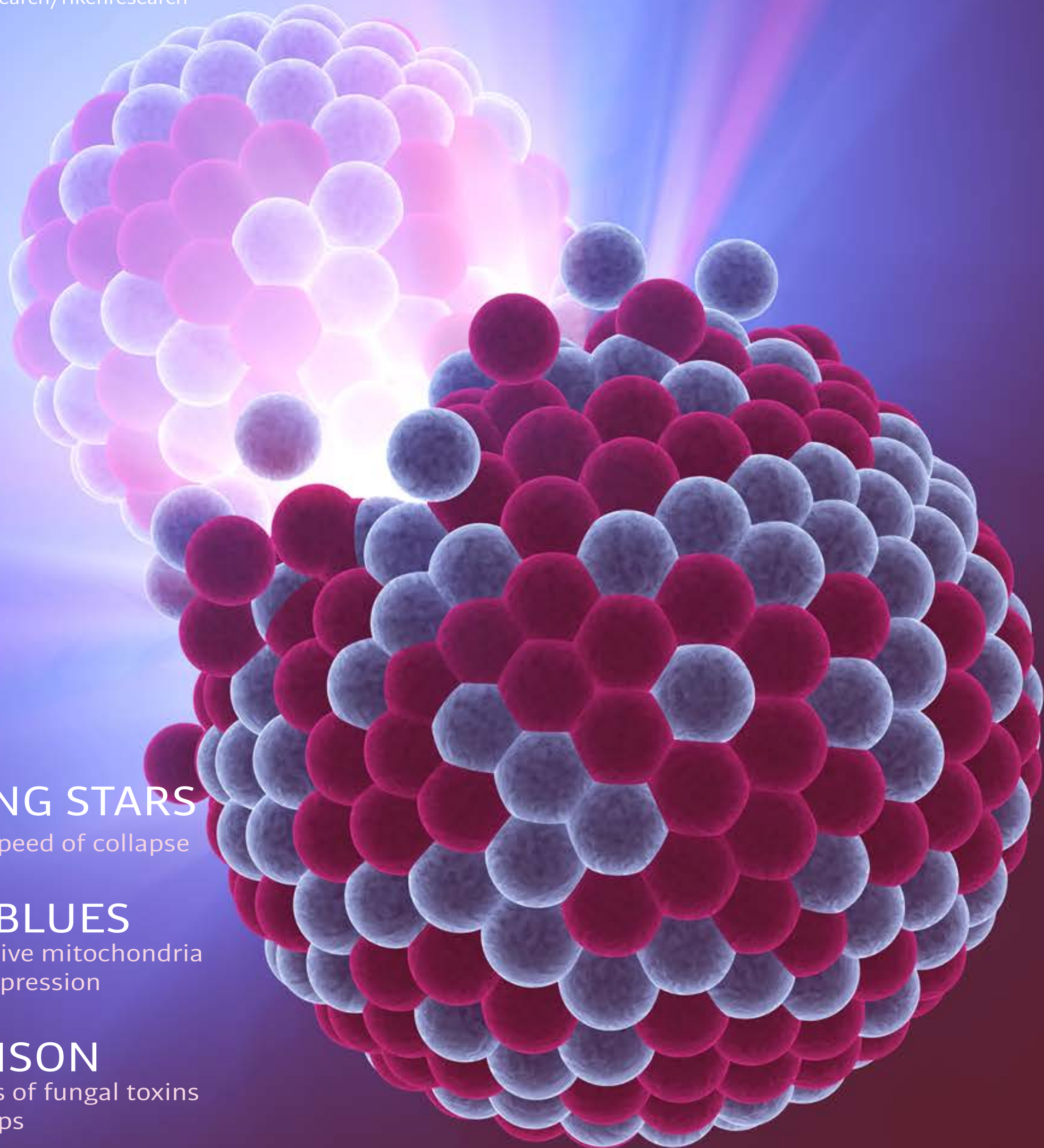

EXPLODING STARS
Simulating the speed of collapse

RODENT BLUES
Mice with defective mitochondria show signs of depression

FOOD POISON
The genetic basis of fungal toxins that damage crops

ELEMENT 113: IN WITH A BANG

RIKEN becomes the first institute in Asia to discover an element

Heavy-ion particle accelerator
The RIKEN heavy-ion linear accelerator (RILAC) was used by Kosuke Morita and his colleagues at RIKEN to bombard a beam of zinc atoms against a bismuth target, which led to the discovery of element 113.

RIKEN, Japan's flagship research institute, conducts basic and applied experimental research in a wide range of science and technology fields including physics, chemistry, medical science, biology and engineering.

Initially established as a private research foundation in Tokyo in 1917, RIKEN became a national research and development institute in 2015.

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For further information on the research presented in this publication or to arrange an interview with a researcher, please contact:

RIKEN Global Relations and Research Coordination Office
2-1, Hirosawa, Wako, Saitama,
351-0198, Japan
Tel: +81 48 462 1225
Fax: +81 48 463 3687
E-mail: rikenresearch@riken.jp

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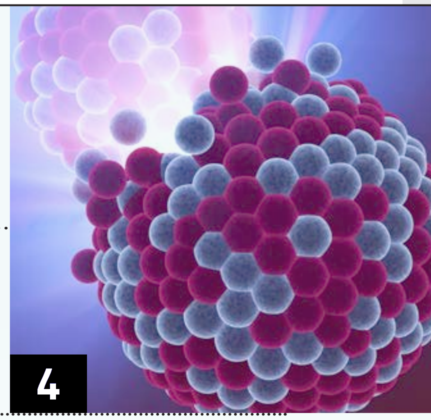

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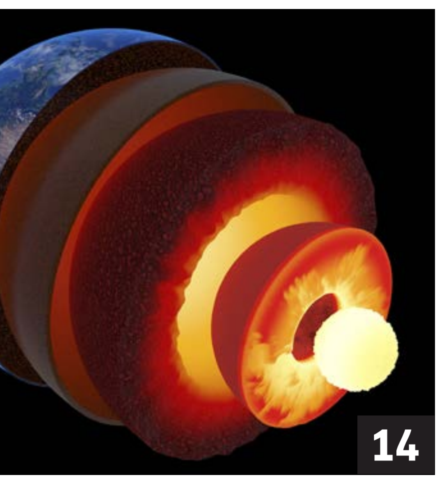

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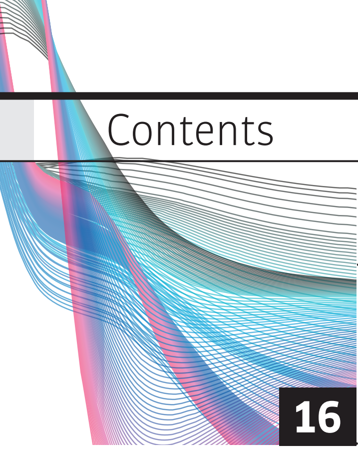
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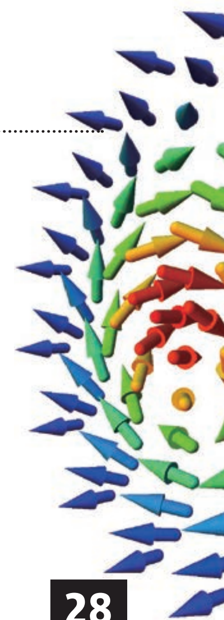
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A day to remember

Cover story: Researchers at RIKEN are formally recognized for their discovery of element 113. **Page 4**

Every year since 1995, the city of Nantes in France has organized one of the world's biggest festivals for classical music—La Folle Journée. The popular event is named after Mozart's opera *The Marriage of Figaro*, also known as 'the day's follies or madness'. Audiences of all ages enjoy short concerts by top musicians at affordable prices, making classical music accessible to all. The concept has since spread to many cities around the world: Madrid, Bilbao, Rio de Janeiro, Warsaw and even Tokyo. This May 2016, La Folle Journée au Japon will be organized under the theme of 'la nature'.

Natural phenomena have inspired composers from the Renaissance period to modern times, including Claude Debussy, Maurice Ravel and Toru Takemitsu. Nature also inspires scientists to conduct research with the same enthusiasm.

In the spirit of the festival, researchers at RIKEN are working hard to make science more accessible to society. And New Year's Eve 2015 offered the perfect example of this, as RIKEN became the first institute in Asia to add an element to the periodic table.

Kosuke Morita and his group at the RIKEN Nishina Center for Accelerator-Based Science were formally recognized by a Joint Working Party of the International Union of Pure and Applied Chemistry and the International Union of Pure and Applied Physics as having synthesized and discovered element 113. They successfully observed the element in 2004, 2005, and then seven years later, in 2012.

The discovery rights of three more elements—115, 117 and 118—were also granted on the same day to a joint group from Russia and the United States, thus completing the seventh row of the periodic table.

We hope that this milestone in the history of science will not only bring fresh hope to scientists across Asia but will also inspire children and the general public to take a greater interest in science.

RIKEN discovers superheavy element 113

Researchers at RIKEN will be the first in Asia to name an element in the periodic table

On New Year's Eve 2015, a group of researchers at the RIKEN Nishina Center for Accelerator-Based Science received news of historical scientific importance to Japan and the rest of the world. The International Union of Pure and Applied Chemistry (IUPAC) would be giving RIKEN's research group the honor of naming and determining the two-letter symbol for element 113. The news came more than 11 years after the RIKEN group, led by Kosuke Morita, first synthesized the element, and 3 years after they had conclusively demonstrated its decay chain. Element 113 will be the first element named by an Asian research institution.

Kosuke Morita's group at the RIKEN Nishina Center for Accelerator-Based Science discovered element 113 using the gas-filled recoil ion separator (GARIS).

Inside the atom

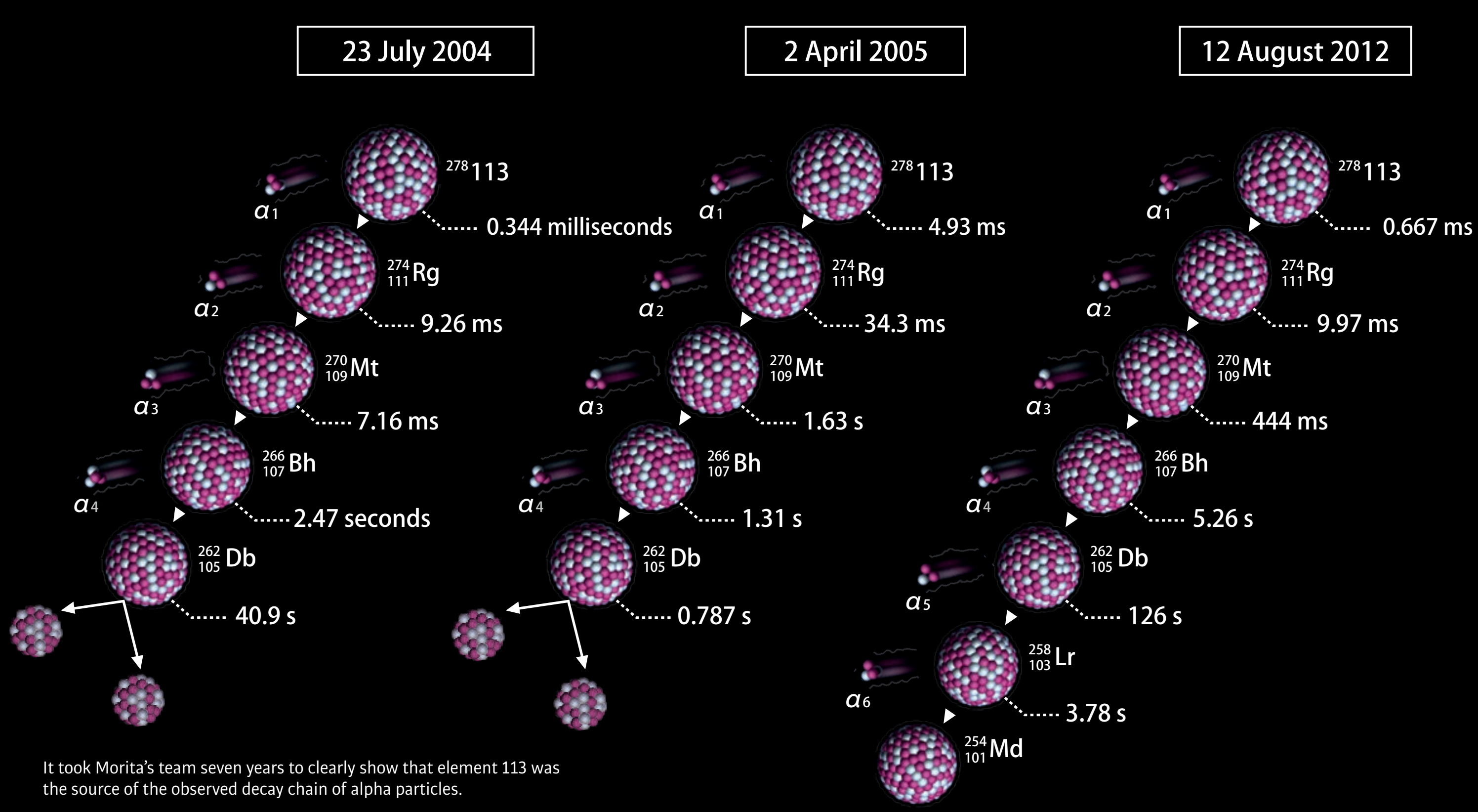
Superheavy elements exist for only a fraction of a second, which makes it very difficult to prove their existence. But studying these evasive atomic species is important for understanding the structure of the atomic nucleus, and could eventually lead to the discovery of the so-called island of stability, where elements with longer half-lives are predicted to exist.

Japan has a long tradition of research in nuclear physics, beginning at the turn of the 20th century with physicist Hantaro Nagaoka, who published an early model of the atom consisting of a small positively charged core, representing the nucleus, with surrounding electrons, similar to the Solar System. Several prominent researchers at RIKEN have made significant theoretical contributions to the field, including the "founder of modern physics in Japan", Yoshio Nishina, as well as the first and second Japanese Nobel laureates, Hideki Yukawa and Shinichiro Tomonaga, respectively. On the experimental side, in 1937 RIKEN became home to Japan's first cyclotron, which was an important pillar for nuclear physics research.

Over the years, RIKEN has developed the ability to design the world's best-performing accelerators, thereby propelling itself to a leading global position in the field. Building on these achievements, RIKEN was able to not just discover element 113, but to also collect additional data on element 112, giving further credibility to the discovery claims of the GSI Helmholtz Center for Heavy Ion Research in Germany.

Hide and seek

The search for element 113 began in September 2003, when Morita's group used the RIKEN heavy-ion linear accelerator (RILAC) to fuse a bismuth nucleus with a zinc nucleus traveling at about 10 per cent of the speed of light, and then used the gas-filled recoil ion



It took Morita's team seven years to clearly show that element 113 was the source of the observed decay chain of alpha particles.

separator (GARIS) to identify the products. By smashing the two lighter elements together, they hoped to produce the heavier element 113.

Morita succeeded in observing a signature of element 113 in 2004, and then again in 2005. The proof came in the form of alpha particles, composed of two protons and two neutrons, emitted as a heavy nucleus decays into a lighter one. Through his high-speed experiments, Morita was able to detect four alpha particles at times corresponding to element 113 decaying sequentially to dubnium-262 (element 105). The dubnium-262 atom then spontaneously split into two smaller fragments, a process known as fission. But neither these results nor the results produced by a separate group of researchers in Russia and the United States were enough to convince the IUPAC that the chain of alpha decays had been produced by element 113.

To form a better picture of the section of the decay chain from bohrium-266 (element 107) to lawrencium-258 (element 103), which had not been previously well characterized, the group performed a new experiment. They bombarded a curium target with a sodium beam to create bohrium-266 and its daughter nucleus, dubnium-262. With this demonstration, the grounds for a stronger claim were laid. The researchers just needed to wait to see element 113 decay passed dubnium-262 through the alpha chain rather than through fission.

But it would be another seven years before they could observe the signature of element 113 once again. "I was not prepared to give up," says Morita. "I believed that one day, if we persevered, luck would fall upon us again."

Naming rights

Finally, on 12 August 2012, Morita's group measured a sequence of six alpha particles that clearly showed that element 113 was the source of the decay chain. This time, following the four initial decays, dubnium-262 continued to undergo two more alpha decays, transforming into lawrencium-258 and then mendelevium-254 (element 101). The results provided sufficient evidence for the IUPAC to recognize Morita's group with the discovery of element 113, and to give them the privilege of naming it.

"We must also keep in mind that this achievement was made possible not by the Morita group alone, but also by a decade of effort by RIKEN's Accelerator Group," notes Hideto En'yo, director of the RIKEN Nishina Center for Accelerator-Based Science. Researchers and technicians at the Accelerator Group, in collaboration with industry, have managed to increase the beam intensity a thousand-fold compared to the first GARIS system built in 1987, and have made it possible to carry out experiments on a 24-hour basis.

"I am proud to know that Japan and RIKEN have produced something that will be added to the list of things that make up the Universe," says RIKEN President Hiroshi Matsumoto. "The Japanese people share in this pride, and I hope the acknowledgement of Japan's role in the discovery of element 113 will stimulate greater interest in science among people in general and children in particular."

While the world focuses its attention on the new name that will be given to element 113, Morita is moving on to the next challenge. "We plan to look to the uncharted territory of element 119 and beyond, aiming to examine the chemical properties of the elements in the seventh and eighth rows of the periodic table, and someday to discover the island of stability," he says.

A twenty-first-century alchemist

Kosuke Morita

Group Leader

Research Group for Superheavy Element
RIKEN Nishina Center for Accelerator-Based Science

Why did you become a scientist?
As a child, I enjoyed observing the Moon, and I remember building a radio using a germanium diode. But what really got me interested in science was when I took physics in high school. I found it fascinating that the world could be described so precisely using mathematics. I recall using an experimental device, often called 'the monkey and the hunter', in which a target is dropped at the same instant a ball is fired directly at it. The ball ends up hitting the target a 100 per cent of the time.

But science didn't prove to be a smooth path for me. As an undergraduate student majoring in physics, there were lots of things I didn't understand, especially in the areas of electromagnetism and quantum mechanics. Also, I was on the judo team, and the chokeholds must have been killing my brain cells, because I felt like I was getting dumber and dumber. I managed to get into graduate school and completed the coursework, but I wasn't able to finish my thesis—I just couldn't get it on paper.

How did you end up working on superheavy elements?
I didn't feel qualified to become a full-fledged physicist, but I was really interested in nuclear physics, so I decided to join RIKEN. At the time, there were plans to conduct experiments on superheavy elements using the ring cyclotron that was under construction.

How did you discover element 113?
In 1987, I built a new device called the gas-filled recoil ion separator (GARIS), which we first used to create elements that other groups had already found. Then we started working on element 113, the first in line of undiscovered elements in the periodic table. But it took more than 11 years for us to find conclusive evidence of its existence.

From a nuclear physics perspective, our work might not be tremendously interesting because we discovered only one of 3,000 nuclides observed so far. But from the viewpoint of chemistry, it is very important, since we are filling in one of maybe only 173 spaces in the periodic table. Fewer than 120 elements have been discovered so far. The discovery of element 113 is also symbolically important because it is the first element to be discovered in Asia.

We are filling in one of maybe only 173 spaces in the periodic table. Fewer than 120 elements have been discovered so far. ”

Is it true that before the discovery you would always give an offering of 113 yen when visiting shrines?
Yes. I wanted to do everything humanly possible to get credit for the element.

What will be your next challenge?
I'd like to go after even heavier elements like 119 and 120, but we will have to use a different process known as hot fusion.

In a sense, we are doing what the early alchemists were trying to do. In fact, Ernest Rutherford, the New Zealand-born chemist who confirmed the existence of the atomic nucleus in 1911, used to say in his lectures that chemists had finally achieved what alchemists had always wanted to do.

This is an edited excerpt of an interview with Kosuke Morita first published in RIKEN's internal newsletter, RIKENETIC.

Element 113 makes headlines

The news that a group of researchers at RIKEN had been officially recognized as having discovered element 113 traveled like lightning through the various Japanese and international research communities, news agencies and the wider public.

Early in the morning of 31 December 2015, the scientific body charged with naming elements—the International Union of Pure and Applied Chemistry (IUPAC)—informed group leader Kosuke Morita (see photo, center) of their decision. He shared the happy news with communications staff at RIKEN, who quickly sent out press releases to journalists and publicized the details on the RIKEN website. Meanwhile, Morita flew from Fukuoka—where he lives—to Tokyo for a press conference being hastily convened for that evening.

RIKEN President Hiroshi Matsumoto (see photo, left), RIKEN Nishina Center for Accelerator-Based Science Director Hideto En'yo (see photo, right) and close to 40 journalists also converged on the press conference. Around seven television crews filmed the event, interrupting their traditional New Year's Eve shows to broadcast the story.

The announcement appeared as a news flash during the popular singing contest *Kohaku* produced by Japan's sole public broadcaster, which close to 40 per cent of households watch across the country. It made front-page news in several national newspapers on New Year's Day. Outside Japan, the Associated Press published a story on the discovery, which featured in a number of online newspapers. A second wave of stories made headlines in all the major news outlets just as the world was returning to work on 4 January, including *Nature*, *Science*, *The New York Times*, *Washington Post*, *Financial Times*, *the Guardian*, *Forbes*, *The Atlantic*, *CNN*, *BBC*, *Fox News*, and of course many newspapers in Asia. In Russia too it was heavily covered—perhaps partly because three other new elements were officially recognized as having been discovered by Russian and US groups.

The global excitement has since calmed down, and Morita has already begun working on one of the major tasks he'll have this year: settling on a name to propose for the element. Ultimately, his research group will propose a name to the IUPAC, which the IUPAC will then present for public review.

www.riken.jp/en/pr/press/2015/20151231_1/

Seeing through steel and concrete

Yoshie Otake

Team Leader

Neutron Beam Technology Team
RIKEN Center for Advanced Photonics

Please describe your research.

Beams of subatomic particles known as neutrons can be used to nondestructively probe the structure and composition of materials. These uncharged neutrons can penetrate heavy elements, seeing through 3-centimeter-thick steel plates and 50-centimeter-thick concrete slabs. Neutron beams can also be used to detect light elements such as hydrogen, lithium and boron. But researchers have not been able to develop a convenient system that can be used anywhere and anytime.

My team is developing compact, accelerator-driven neutron sources for practical applications. We want to use these systems to assess the inner condition of large infrastructure projects such as highways and bridges that are nearing the end of their life cycles.

When did you join RIKEN?

In 1996, I joined a team of researchers at RIKEN collaborating with the Japan Atomic Energy Research Institute (now reorganized into the Japan Atomic Energy Agency) and tasked with constructing the synchrotron radiation facility at Harima, SPring-8 (Super Photon Ring-8 GeV).

How did you become interested in your current field of research?

I have enjoyed physics since high school. I am especially interested in observing coherent behavior in the quantum states of neutrons and searching for the breaking of time-reversal symmetry in the electric dipole moment of the neutron.

Through working on neutron experiments and nuclear reactors that serve as sources of neutrons for research, I became interested in neutron imaging and potential industrial uses of compact neutron sources. I cultivated this interest through a collaboration with the RIKEN VCAD System Research Program, which ran from 2001 to 2011. The project sought to develop a method for modeling and simulating both the shape and volume of an object for use in manufacturing, medicine and the biosciences.

> *We want to use these systems to assess the inner condition of large infrastructure projects.*

What have been your most memorable experiences at RIKEN?

I get excited when I discover new ways of making neutron beams more compact or neutron detection easier. I also really enjoy discussing with industry representatives about ways of using our systems to nondestructively inspect their products.

In 2013, we collaborated with several RIKEN groups to develop the first compact neutron source specifically designed for practical use by industry, named RANS (RIKEN accelerator-driven compact neutron source). RANS was used to visualize, for the first time in the world, corrosion and water volume in painted steel, working with members of a research group at the Iron and Steel Institute of Japan. In 2015, RIKEN constructed a new building for RANS. Nowadays, getting the approval and budget to construct an entirely new building is rare, and that too just for one team.

What is the best thing about working at RIKEN?

The best thing about being a researcher at RIKEN is its free and engaging atmosphere. We can discuss many areas of interest with high-level researchers and have the flexibility to start new research projects.

What has been the most interesting recent discovery in your field?

In 2015, Takaaki Kajita and Arthur McDonald won the Nobel Prize in Physics for discovering that elementary particles called neutrinos oscillate between different identities, and hence have mass. This finding contradicts the Standard Model of particle physics, which requires neutrinos to be massless.

Careers at RIKEN

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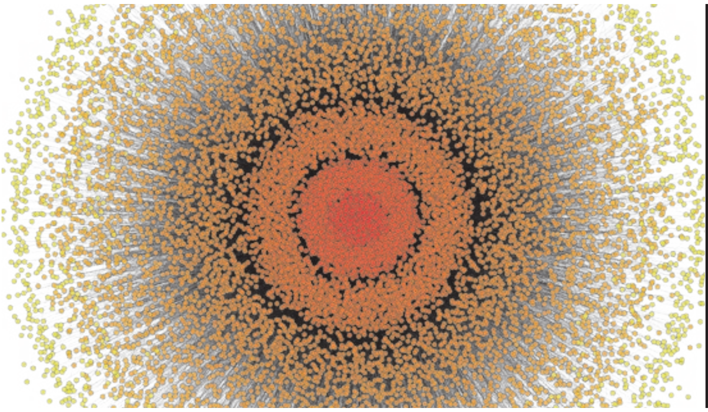
K computer comes first again

The K computer won first place in the Graph 500 supercomputer ranking for the second time in a row, demonstrating its prowess in data-intensive processing. The feat was the result of a strong collaboration between RIKEN, Tokyo Institute of Technology (Tokyo Tech), University College Dublin, Kyushu University and Fujitsu. “I am delighted that we have been able to take the top spot again, after winning it in July,” says Koji Ueno of RIKEN and Tokyo Tech, who led the team.

The Graph 500 is a relatively new benchmark, first launched in 2010 to test the suitability of supercomputers for data-intensive applications. The ranking aims to improve computing of complex data problems in areas such as cybersecurity, medical informatics, social networks and modeling neuronal circuits in the brain.



An illustration of an extremely large data set with 16,000 edges. The Graph 500 challenge required supercomputers to solve a search of a graph with 16 trillion edges, which the K computer performed in 0.45 seconds.

As part of the Graph 500 challenge, the international team had to use the K computer to solve a search of an extremely large data set known as a graph, made up of 1 trillion nodes and 16 trillion connecting edges. They completed the task in an astounding 0.45 seconds, using 82,944 of the K computer’s 88,128 processing units. Final scores were announced at an international conference in Austin, United States, on 17 November 2015.

www.riken.jp/en/pr/topics/2015/20151118_1/

Pioneering stem cell study passes one-year milestone

One year after undergoing surgery, the first patient in the world to receive a tissue transplant derived from induced pluripotent stem (iPS) cells is doing well, announced the RIKEN Center for Developmental Biology (CDB), the Foundation for Biomedical Research and Innovation (FBRI) and Kobe City Medical Center General Hospital in October 2015. The clinical study is testing the safety of iPS cell-based interventions for the treatment of a common eye disease called age-related macular degeneration.

One year on, the patient has experienced no major side effects, shows no signs of tumor formation, and retains viable transplanted cells, reports Yasuo Kurimoto (see image, left), an ophthalmologist at the FBRI who headed the surgical team. The patient’s vision, which was deteriorating before the procedure, has remained stable since the operation. However, Kurimoto emphasized that this might be due to the removal of excess blood vessels formed in the retinal tissue.

Masayo Takahashi (see image, right) of the CDB was happy with the outcome. “I am eager to continue moving forward until we can make this treatment available to many patients with age-related macular degeneration,” she says.

www.riken.jp/en/pr/topics/2015/20151015_1/

Seeing into the primate brain

Researchers at the RIKEN Brain Science Institute have developed a real-time imaging system capable of imaging hundreds of neurons in the marmoset brain over several months. The system can be used to study complex cognitive and social behaviors shared by non-human primates. “We will be able to investigate how primate brains work at a level not previously possible,” says Tetsuo Yamamori, who led the study.

The system uses a technique known as two-photon microscopy, which involves genetically tagging a molecule of interest with compounds that fluoresce when excited by light from an infrared laser. To visualize neuronal activity, researchers attach these fluorescent compounds to molecules that bind to calcium, which is released during neuronal signaling. The fluorescence signals are typically bright enough to be detected in the brains of small animals such as mice, but too weak to see in primate brains.

The RIKEN researchers dramatically boosted the fluorescence levels by using viral vectors, which incorporate the so-called Tet-Off system to express the calcium sensors in the marmoset brains. They also modified the transgenes so that they fluoresce only when the antibiotic doxycycline is not present. By adding doxycycline to the monkeys’ drinking water, the research team could halt transgene expression for several weeks, and thus prevent neuronal damage and enable long-term imaging.

www.riken.jp/en/pr/press/2015/20151120_2

RIKEN deepens collaboration with South Korean science institute

RIKEN and the South Korean Institute for Basic Science (IBS) signed their first comprehensive research agreement in a ceremony held on 25 November 2015 in Wako city, near Tokyo. The signing ceremony was attended by a delegation from South Korea, including Minister of Science, ICT and Future Planning Yanghee Choi (see photo, center) and IBS President Doochul Kim (see photo, right).

At the ceremony, RIKEN President Hiroshi Matsumoto (see photo, left) welcomed the delegates and briefly introduced the comprehensive research institute. Minister Choi expressed his wish that the delegation would learn from RIKEN's long history of contribution to the sciences, dating back nearly a 100 years. He noted that IBS, founded in 2011, had been modeled on RIKEN and the Max Planck Society, and hoped that RIKEN and IBS would deepen their partnership to contribute to society and humanity. In his address, President Kim said he was looking forward to expanding the collaboration between the two institutes, by engaging at all levels, from the laboratory level to the institutional level.

Following the ceremony, the delegation toured the RIKEN Nishina Center for Accelerator-Based Science, which is home to the heavy-ion research facility, the Radioactive Isotope Beam Factory. The Nishina Center conducts joint research with the Rare Isotope Science Project at IBS.

www.riken.jp/en/pr/topics/2015/20151126_2/

Forging ties with Luxembourg

RIKEN and the Luxembourg National Research Fund (FNR) signed a memorandum of understanding at a ceremony in Tokyo attended by Luxembourg Ambassador to Japan Béatrice Kirsch (third from left), FNR Secretary General Marc Schiltz and RIKEN Executive Directors Shigeo Koyasu and Sawako Hanyu.

On 7 October 2015, representatives from RIKEN and the Luxembourg National Research Fund (FNR) gathered at the Luxembourg Embassy in Tokyo to sign a memorandum of understanding, in which the two institutions pledged to encourage cooperation in science and technology between RIKEN and public research institutions in Luxembourg. The agreement covers all areas of science, with a special focus on immunology and systems biology.

The ceremony was also attended by Luxembourg Ambassador to Japan Béatrice Kirsch, researchers from Luxembourg, and a former ambassador.

The event was held in conjunction with a visit by researchers from the Luxembourg Center for Systems Biomedicine, University of Luxembourg, which has already established a fruitful relationship with the RIKEN Center for Integrative Medical Sciences (IMS). Members of the Luxembourg Institute of Health were also present, hoping to forge new ties with Japanese institutions.

On the following day, representatives from the two Luxembourg institutions were given a tour of the IMS facilities in Yokohama and attended a mini-workshop, where they discussed the potential for future research collaborations.

http://www.riken.jp/en/pr/topics/2015/20151013_1/

Global research summit commits to increased collaboration

Representatives from 18 scientific research institutes based in 13 countries around the world congregated in Kyoto on 3 October 2015 to attend the Fourth Global Summit of Research Institute Leaders. The meeting has been held annually since 2012 to give heads of research institutes a forum for discussing shared problems and building strategies for cooperation to better contribute to the advancement of society. The summit was held in conjunction with the Science and Technology in Society *forum*.

RIKEN and the National Institute of Advanced Industrial Science and Technology in Japan jointly hosted the meeting, which was co-chaired by RIKEN President Hiroshi Matsumoto and Alain Fuchs, president of the National Center for Scientific Research in France. Stefan Noreén, former Swedish ambassador to Japan, acted as facilitator.

The focus this year was on collaboration. Participants exchanged ideas, such as on the establishment of large-scale facilities shared by researchers from many institutes and universities, and the development of joint programs for nurturing young researchers. The meeting ended with the adoption of a statement recognizing the importance of such partnerships and calling for increased cooperation through shared facilities and personnel, including cross appointments, joint laboratories, and hosting faculty members and graduate students.

www.riken.jp/en/pr/topics/2015/20151019_1/

RIKEN–Academia Sinica Joint Conference on Chemical Biology

On 15–16 October 2015, Academia Sinica hosted the second RIKEN–Academia Sinica Joint Conference on Chemical Biology in Taiwan.

The two institutes have been cooperating in the field since 2001. Academia Sinica President Chi-Huey Wong welcomed the gathering of around 100 participants, including many students. President Wong and science advisor to RIKEN, Tomoya Ogawa, co-chaired the event.

The conference featured presentations by ten RIKEN researchers from the RIKEN Center for Sustainable Resource Science, RIKEN–Max Planck Joint Research Center for Systems Chemical Biology, and RIKEN's Chief Scientist Laboratories, as well as ten presentations from Academia Sinica's Genomics Research Center, Institute of Biological Chemistry, and Institute of Chemistry. Speakers introduced their research, ranging from the regulation of hypoxia to the development of novel drugs for Alzheimer's disease, cancer and influenza.

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The type 2 innate immune response fights dangerous pathogens, but it can cause allergies such as asthma if not turned off.

BIOLOGY | PRESS RELEASES

Switching off innate immunity

Scientists discover how the type 2 innate immune response is turned off after infections

The innate immune response—the body's rapid and non-specific response to pathogens—was once believed to be a simple system relying solely on short-lived effector cells. It is now known to be more complex, involving long-lived lymphoid cells. RIKEN researchers have shown how the body suppresses the activation of these long-lived cells after infection has been stopped, preventing the response from continuing when it is no longer needed.

Parasitic worms pose a formidable threat to human health, being a major cause of mortality in the developing world. The body's key first-line defense against these parasites and some fungal infections, called the type 2 innate immune response, precedes a more specific response called the type 2 adaptive immune response and has been implicated in allergic inflammatory responses such as asthma.

"This immune response is important, but it can also be dangerous if it lasts beyond when it's needed," explains Kazuyo Moro of the RIKEN Center for Integrative Medical Sciences. "It was once believed that the response was mainly mounted by short-lived cells, but we now know that it also involves a population of longer lived innate lymphoid cells. Since a continuing response is associated with allergic inflammation, it is important to understand how these cells are turned off."

Moro and her co-workers found that certain cytokine chemicals shut off these innate lymphoid cells to stop the immune response and ensure that inflammation does not last[1]. In addition, they have cleared up a mystery about these cells by showing that they do not circulate to tissues that require an immune response but are located in the tissues themselves, and are only turned on when a threat is detected.

"This shows that the response is mounted in a very local, specific way," says Moro. "This may be another way for the body to prevent ongoing inflammation that can be associated with the response."

The findings are helpful for understanding how the changes to the type 2 innate response are both beneficial and harmful. "Learning how these cells are activated and inactivated can provide clues for understanding and treating how the body reacts to such infections," says Shigeo Koyasu, who led the group. "We are beginning to gain insights into the innate immune response. I hope that our work will encourage researchers to look for similar regulatory mechanisms in type 1 and 3 innate immune responses as well, as this will help us to gain a broader understanding of the complexity of our immune response." ■

Reference

1. Moro, K., Kabata, H., Tanabe, M., Koga, S., Takeno, N., Mochizuki, M., Fukunaga, K., Asano, K., Betsuyaku, T. & Koyasu, S. Interferon and IL-27 antagonize the function of group 2 innate lymphoid cells and type 2 innate immune responses. *Nature Immunology* **17,** 76–86 (2015).

PHYSICS

Characterizing electrons in the smallest devices

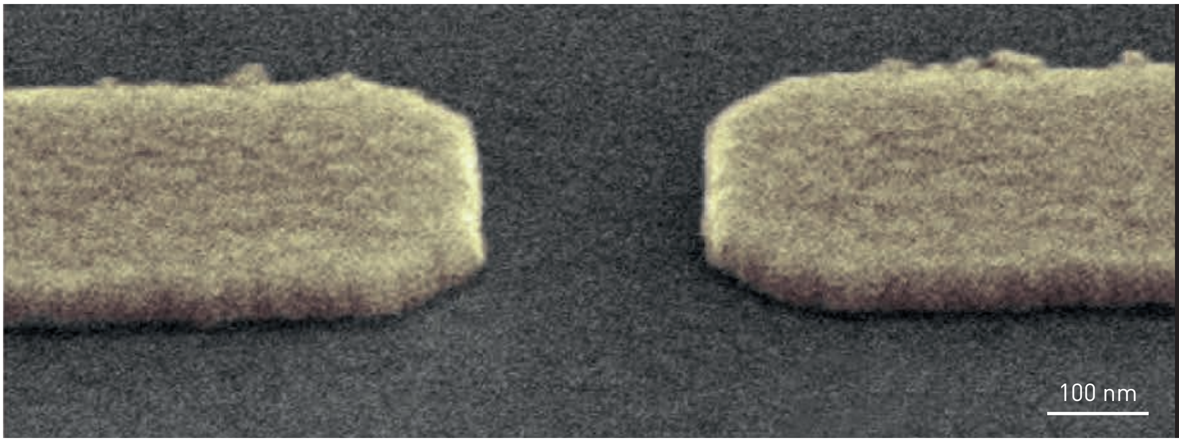
A technique for investigating the magnetic properties of electrons in quantum point contacts leads to a better understanding of these quantum devices

A way to use nuclear magnetic resonance (NMR) spectroscopy to investigate electron spin in nanoscale electronic devices has been developed by RIKEN researchers.

The control of electric currents underpins all electronic devices. The most fundamental form of modifying electronic currents occurs in quantum point contacts (QPCs)—devices that have a narrow constriction between two wide electrically conducting regions (see image). Since the constriction width is comparable to the electron wavelength, quantum effects come into play and control electron movement.

One manifestation of this is that the electrical conductance of a QPC increases in regularly spaced steps as the voltage across it is increased. Additionally, an anomalous small increase in the conductance is observed at 70 per cent of the voltage at which the first step appears. The origin of this anomaly is not fully understood, but theoretical studies have suggested that it is related to electron spin.

While NMR spectroscopy can be used to investigate spin properties, it is not sensitive enough to analyze objects as small as QPCs. Now, Minoru Kawamura and his colleagues at the RIKEN Center for Emergent Matter Science, together with researchers at the Slovak Academy of Sciences and Ibaraki University have developed a way to use NMR spectroscopy to measure the magnetic properties of electrons in QPCs, enabling them to obtain a better understanding of these devices[1].



The narrow constriction in a quantum point contact (defined by the two contacts on the substrate) gives rise to quantum phenomena, which can now be explored by measuring conductance and nuclear magnetic resonance signals.

The researchers found that the spin of electrons in a QPC affects the way atomic nuclei respond to NMR signals, resulting in a slight shift in the NMR frequency. This frequency shift in turn measurably alters the electrical conductance of a QPC. Thus, the scientists could evaluate the properties of electronic spins by measuring the NMR signal in combination with variations in the electrical conductance. This new technique allows the magnetization of a few electron spins to be measured.

The team used this method to shed light on the nature of the additional quantum step in the conductance at 70 per cent of the regular step voltage. Their results eliminated an electronic state that had been previously proposed to promote electron conductance at this low voltage; instead, the signal appears to arise from other electronic interactions across the QPC.

The researchers are excited about the potential of their method to probe other ultrasmall devices. "The present technique can open the way for studying the magnetic properties of nanoscale devices and materials such as nanowires or nanoflakes," comments Kawamura. ■

Reference

1. Kawamura, M., Ono, K., Stano, P., Kono, K. & Aono, T. Electronic magnetization of a quantum point contact measured by nuclear magnetic resonance. *Physical Review Letters* **115,** 036601 (2015).

PHYSICS | PRESS RELEASE

Probing the Earth's liquid core

By measuring liquids under extremely high pressures and temperatures, scientist have gleaned valuable clues into the composition of the Earth's core

Measurements of how seismic acoustic waves—such as those created by earthquakes—travel through the Earth indicate that 95 per cent of the Earth's core is liquid, but they do not reveal its chemical composition. Now, RIKEN researchers, along with collaborators, have measured the speed of sound in mixtures of liquid iron and carbon under extreme conditions, allowing limits to be set on the composition of the Earth's core.

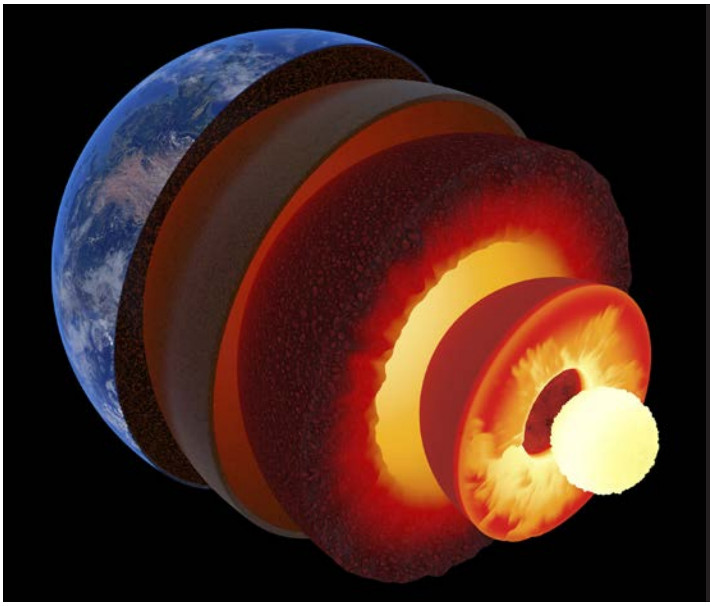
"Understanding the composition of the liquid in the Earth's core is important, as it can give clues about how the Earth formed," explains Alfred Baron of the RIKEN SPring-8 Center.

The liquid in the core is known to be mostly molten iron, but its density is about 10 per cent too low to be only iron. Thus, geoscientists are seeking to determine what other elements are mixed with the iron.

Researchers around the world are now compiling a catalogue that matches sound velocities with material composition and temperature. However, measurements are difficult because temperatures inside the Earth can exceed 5,000 kelvin and pressures reach several million atmospheres. Consequently, the catalogue has grown very slowly, with each point requiring man-years of work. Also, despite 95 per cent of the Earth's core being liquid, almost all the measurements so far have been of solids because they are easier to handle.

In the current study, the researchers extended the catalogue to include the first liquid measurements at very high pressure[1]. Using a combination of diamond anvil cell technology (where a sample is squeezed between two diamonds), laser heating and an inelastic scattering spectrometer at SPring-8, they measured the sound velocity of liquid iron–carbon mixtures at very high temperatures and pressures.

While the pressures and temperatures the researchers achieved were only about



The Earth's molten core is known to be mostly made of iron. New measurements on liquids under extreme conditions will assist scientists to ascertain what other elements might also be present.

half those of the outermost part of the liquid core—where the pressure is about 1.3 million atmospheres and the temperature about 4,000 kelvin—they were able to extrapolate to core conditions from the measurements.

"The extrapolation gives us important insights, suggesting that at most only about 1.2 per cent of the core, by weight, is carbon," says Yoichi Nakajima, the first author of the study. "Thus, while there may be, and, in fact, probably is, some carbon in the core, there must also be some other light elements, such as silicon, oxygen, sulfur or hydrogen."

The team intends to continue to work with different materials and even more extreme conditions at a new RIKEN facility, the Quantum NanoDynamics Beamline at SPring-8. ■

Reference

1. Nakajima, Y., Imada, S., Hirose, K., Komabayashi, T., Ozawa, H., Tateno, S., Tsutsui, S., Kuwayama, Y. & Baron, A. Q. R. Carbon-depleted outer core revealed by sound velocity measurements of liquid iron–carbon alloy. *Nature Communications* **6,** 8942 (2015).

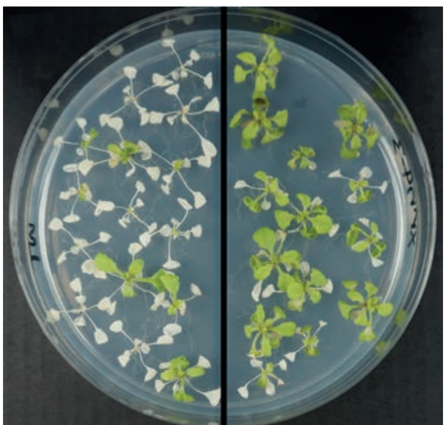
BIOLOGY

Plant stress adaptation in the hot seat

A plant adaptation to heat stress ironically destroys key regulators to heat tolerance

The mass destruction of RNA, which is considered to be a plant adaptation to thermal stress, can sometimes be counterproductive for heat acclimation, find RIKEN researchers.

As sessile organisms, plants cannot move around. But they can respond to adverse environmental conditions by altering the molecular landscape of their cells. When exposed to elevated temperatures, for instance, plants will target several thousand different RNA molecules for rapid degradation.



Seedlings of *Arabidopsis thaliana* without the enzyme Arabidopsis 5'-3' exoribonuclease (AtXRN4) (right) grow better than normal plants (left) when exposed to short-term severe heat stress.

Working with the thale cress *Arabidopsis thaliana*—a model system for plant biology studies—a team led by RIKEN researchers has shown that the enzyme responsible for much of the heat-induced degradation also wipes out several key regulators of heat tolerance[1].

The heat-induced RNA decay is driven by an enzyme known as Arabidopsis 5'-3' exoribonuclease (AtXRN4). To better understand the molecular targets of AtXRN4, Motoaki Seki and his colleagues at the RIKEN Center for Sustainable Resource Science, along with collaborators at other institutions in Japan and Vietnam, studied plant strains with genetic mutations that rendered the AtXRN4 enzyme non-functional. Surprisingly, they found that these mutant plants were more likely to survive after exposure to severe short-term heat stress—temperatures of around 44 degrees Celsius for 3 to 4 hours—than normal plants with a working version of the enzyme (see image).

The researchers compared gene expression patterns in mutant and normal two-week-old seedlings. They found higher expression levels of several heat-stress-responsive genes in the mutant plants, both those subjected to extreme temperatures and those exposed to non-stressed conditions. The most important such gene seemed to be *heat shock factor A2* (*HSFA2*); mutant seedlings lacking both this gene and the one encoding AtXRN4 were no more heat tolerant than normal plants.

These heat-tolerance genes that AtXRN4 usually degrades are beneficial for responding to hot conditions, but their expression can also be maladaptive during times of non-stress-inducing temperatures. The researchers hence concluded that AtXRN4 is required for maintaining a proper balance between the creation and destruction of stress-response RNAs. For instance, AtXRN4 is needed to degrade *HSFA2* mRNA after plants have acclimated to hotter temperatures and returned to normal growth conditions.

"AtXRN4 fine-tunes the rapid and dynamic alteration of gene expression in response to environmental stimuli," explains Seki.

This finding could aid the development of more stress-tolerant crops, which is especially important given the rising temperatures caused by global climate change. For example, plant breeders could tweak AtXRN4 levels to engineer hardier food staples for the agriculture industry. ■

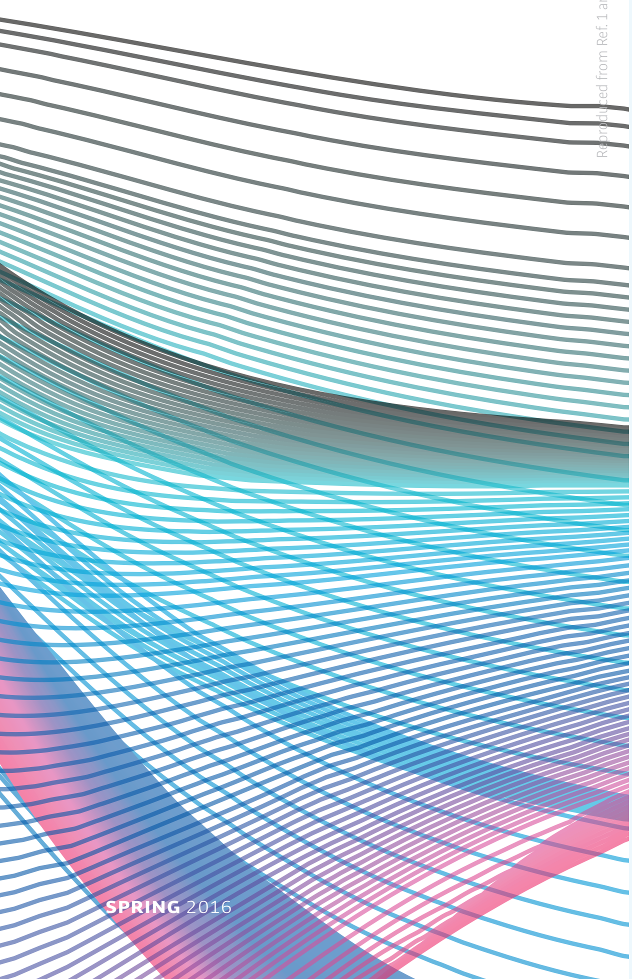
Reference

1. Nguyen, A. H., Matsui, A., Tanaka, M., Mizunashi, K., Nakaminami, K., Hayashi, M., Iida, K., Toyoda, T., Nguyen, D. V. & Seki, M. Loss of Arabidopsis 5'-3' exoribonuclease AtXRN4 function enhances heat stress tolerance of plants subjected to severe heat stress. *Plant & Cell Physiology* **56,** 1762–1772 (2015).

Physics

Defrosting a magnetic mystery

An intriguing quantum effect that is potentially useful for practical electronic devices has been realized at significantly higher temperatures than previously observed



By tweaking the composition and structure of incredibly thin layers of magnetic materials, RIKEN researchers have created devices that make it easier to study a recently discovered phenomenon known as the quantum anomalous Hall effect (QAHE). First observed in 2013, the QAHE causes electrons to flow in unusual ways. The RIKEN devices could reveal exotic physics that might be harnessed for low-power electronics.

Electrons are negatively charged particles that carry electrical current through a conductor. Applying a strong magnetic field at right angles to the current causes the electrons to veer toward one side of the conductor, thereby creating a voltage difference between the conductor's two sides. This is the Hall effect, first discovered by physicist Edwin Hall in 1879.

The quantum counterpart of this classical effect, the quantum Hall effect (QHE), arises when the conductor is cooled to a low temperature and electrons move through a region with virtually no thickness, such as the interface between two materials. Under these conditions, increasing the magnetic field strength causes the Hall voltage to rise in distinct steps.

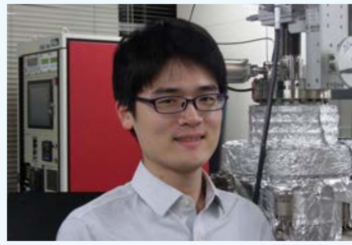
The drifting electrons create their own 'edge current' that flows without energy loss, leading researchers to believe that the QHE could be exploited to build highly efficient electronic devices. But the QHE requires a very strong magnetic field—a serious drawback for practical applications. So scientists have started looking into magnetic materials that exhibit the QAHE, since, unlike the QHE, the QAHE originates from a material's own magnetization. This allows edge currents to be generated without applying a magnetic field.

A class of materials called topological insulators is particularly promising in this area. Their interiors are electrical insulators, but they possess conducting surfaces. Their magnetic properties can be altered by seeding them with traces of elements such as chromium. "When topological insulators are doped with magnetic ions, ferromagnetism emerges in their interiors," says Ryutaro Yoshimi of the RIKEN Center for Emergent Matter Science, who is investigating the QAHE.

Unfortunately, the QAHE has only been observed in topological insulators at extremely low temperatures, typically less than a few tenths of a degree above absolute zero. To study these quantum Hall effects and to make them more practically useful, Yoshimi and his colleagues are trying to raise that temperature. Their approach involves optimizing the composition of topological insulators and then stacking high-quality thin films of these materials. This has allowed them to reduce the crystal defects and structural disorder in these systems, significantly raising the temperature at which the QAHE emerges.

A unique hybrid

In their latest investigation, the researchers studied a topological insulator called bismuth antimony



Ryutaro Yoshimi

Ryutaro Yoshimi was born in Tokyo, Japan, in 1988. He received his bachelor's (2011) and master's (2013) degrees at the University of Tokyo's Department of Applied Physics and is continuing his research as a doctorate student under the supervision of Yoshinori Tokura, director of the RIKEN Center for Emergent Matter Science. He is supported by a Research Fellowship for Young Scientists from the Japan Society for the Promotion of Science, as well as through RIKEN's student trainee program. His current interests include the quantum transport of Dirac electron states at the surface and interface of topological insulators.

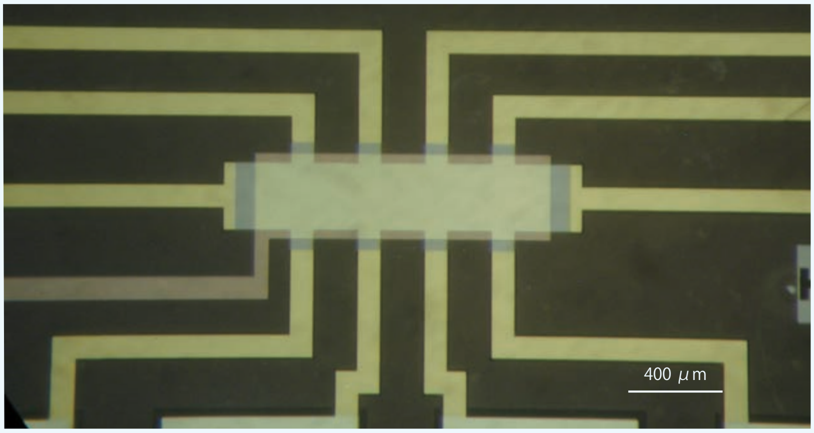


Figure 1: A field-effect transistor containing two layers of topological insulator materials that stabilize quantum Hall states.

telluride (BST). They laid a 5-nanometer-thick film of the material on an indium phosphide substrate and added a 2-nanometer layer of chromium bismuth antimony telluride (CBST) on top. BST is non-magnetic, but adding chromium atoms makes the resulting CBST layer magnetic.

The scientists tested samples with five slightly different chemical compositions and obtained the most promising results from a blend containing just over seven times more antimony than bismuth. They then used BST and CBST films of this composition to create a field-effect transistor (Fig. 1). This enabled the researchers to use a voltage to control the electron density in the materials while using an applied magnetic field to fine-tune the device's quantum Hall properties.

They found evidence of quantum Hall behavior in two parts of the device: on the top surface of the CBST layer and on the bottom of the BST layer. They also discovered that the effect on top of the CBST layer was caused by the material's intrinsic magnetization, whereas the effect below the BST layer was generated by the external magnetic field[1]. "This is a hybrid effect of QHE and QAHE," says Yoshimi. "It has never been observed that two surface states in one thin film quantize with different origins."

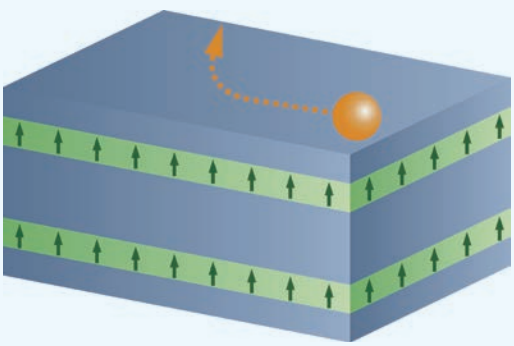


Figure 2: A five-layer structure made of alternating layers of bismuth antimony telluride (blue) and chromium bismuth antimony telluride (green). The structure exhibits the quantum anomalous Hall effect at the unusually high temperature of 1 kelvin, which causes electrons (orange sphere) to move sideways.

Crucially, these quantum Hall states were seen at 2 kelvin, a considerably higher temperature than in single-layer films of BST or CBST. This might be because the two-layer structure avoids some of the disorder that occurs at the interface between a single layer of CBST and its indium phosphide substrate. Yoshimi says that these results could help to design other semimagnetic devices based on topological insulators, and thus allow the behavior of these materials to be explored further.

Layers upon layers

In another recent study, the researchers found that stacking more layers of these materials stabilizes the QAHE at higher temperatures[2]. They compared a single layer of CBST with two other structures: a three-layer structure in which a BST layer is sandwiched between two CBST layers and a five-layer structure of alternating BST and CBST layers (Fig. 2).

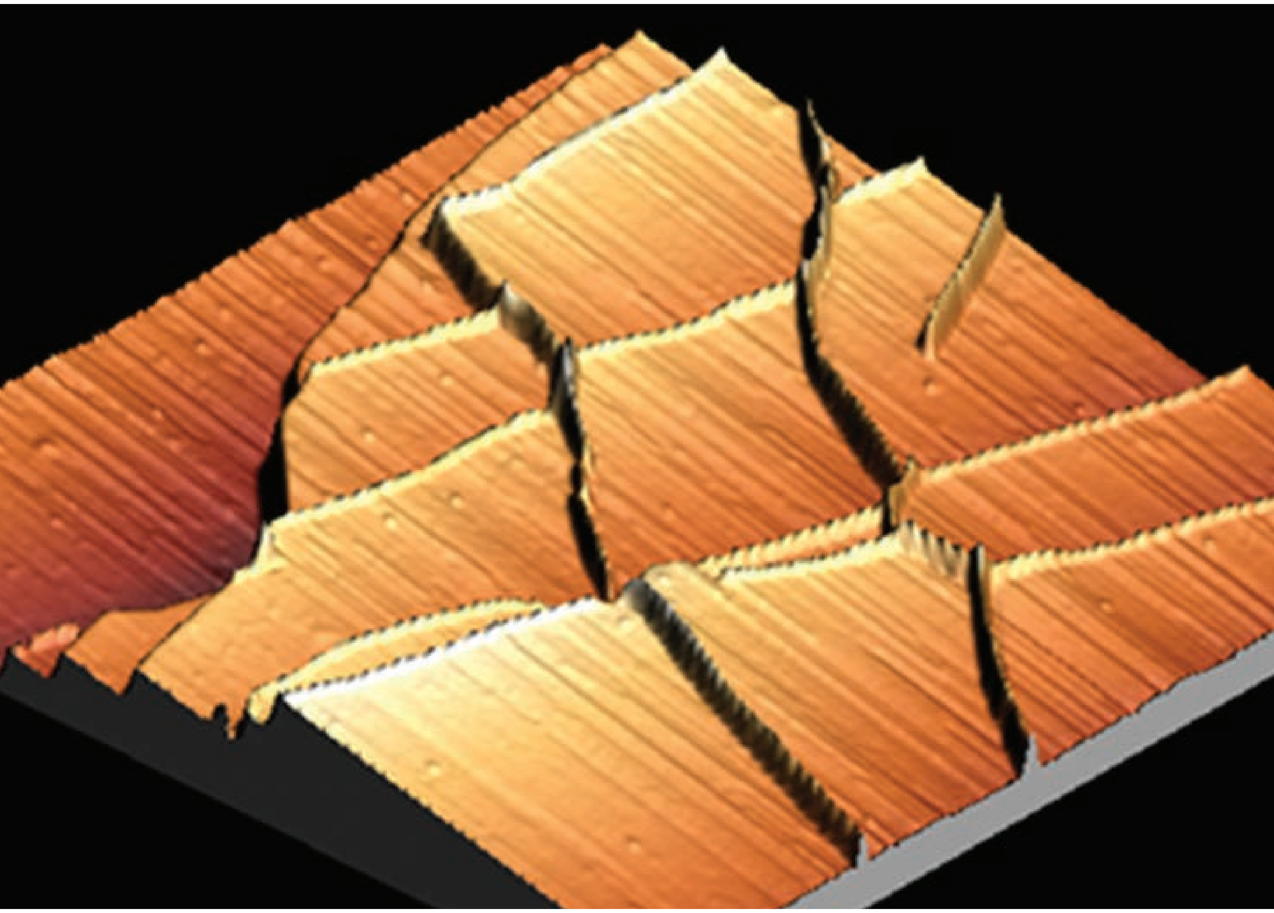
"Chromium concentration is one of the key parameters for maximizing the observable temperature of QAHE in the five-layer system," says Yoshimi. More chromium increases the intrinsic magnetization of the material, which can stabilize the QAHE, but it can also increase disorder at the interface between the layers, which reduces the QAHE. To find the best balance between these two factors, the researchers tested various compositions. They found that the optimum chromium concentration was a little richer than that in their previous experiments.

"By inserting 1-nanometer-thick layers heavily doped with chromium, we stabilized and clearly observed the QAHE up to 1 kelvin," says Yoshimi. That temperature is over ten times higher than that for a single-layer CBST film, and, importantly, it does not require applying an external magnetic field, unlike the above-mentioned CBST two-layer structure. "This paves the way to deepen research on edge currents that flow without dissipating energy in the absence of an external magnetic field and to further explore exotic topological phenomena," he says.

References

1. Yoshimi, R., Yasuda, K., Tsukazaki, A., Takahashi, K. S., Nagaosa, N., Kawasaki, M. & Tokura, Y. Quantum Hall states stabilized in semi-magnetic bilayers of topological insulators. *Nature Communications* **6,** 8530 (2015).

2. Mogi, M., Yoshimi, R., Tsukazaki, A., Yasuda, K., Kozuka, Y., Takahashi, K. S., Kawasaki, M. & Tokura, Y. Magnetic modulation doping in topological insulators toward higher-temperature quantum anomalous Hall effect. *Applied Physics Letters* **107,** 182401 (2015).



Scanning tunneling microscopy image showing nanowrinkles in graphene. These nanowrinkles cause graphene to become semiconducting.

MATERIALS | PRESS RELEASE

Wrinkles make graphene semiconducting

A serendipitous discovery shows that tiny wrinkles in graphene can cause the material to become semiconducting

Wrinkles in graphene can confine the motion of electrons to one dimension, forming a junction-like structure that can be changed from a conductor to a semiconductor and back again, RIKEN scientists have found[1]. Furthermore, the team manipulated the formation of wrinkles using the tip of a scanning tunneling microscope, enabling graphene semiconductors to be produced by a non-chemical method that involves manipulating the carbon structure itself.

Graphene is generally considered to be a two-dimensional material—a single sheet of carbon atoms arranged in a regular structure. But reality is not so simple; wrinkles can form in graphene, imparting it with a more complicated structure. In addition, graphene can interact with its substrate, adding further complexity. The group stumbled on the confining effect of wrinkles on electron flow in graphene while experimenting with creating graphene films using chemical vapor deposition, which is considered the most reliable method to produce graphene. They were trying to form graphene on a nickel substrate but found that the success of this method strongly depended on the temperature and cooling speed.

"We were attempting to grow graphene on a single-crystal nickel substrate, but in many cases we ended up creating a compound of nickel and carbon rather than graphene," describes Hyunseob Lim of RIKEN Surface and Interface Science Laboratory. "To resolve the problem, we tried quickly cooling the sample after dosing it with acetylene. During that process, we accidentally found small nanowrinkles, just five nanometers wide." The researchers imaged these tiny wrinkles using a scanning tunneling microscope (see image) and discovered that they contained band gaps.

Conductors do not have band gaps and hence electrons and electron 'holes' flow freely through them. In contrast, semiconductors possess band gaps and consequently electrons can flow in them only under certain conditions. Thus, wrinkles can cause graphene to behave as a semiconductor.

The team concluded the band gap was caused by the wrinkles restricting electrons to a single dimension as a result of an effect known as quantum confinement.

This finding opens a new way to control graphene's electronic properties. "Until now, efforts to manipulate the electronic properties of graphene have principally been done through chemical means, but chemical defects can lead to degraded electronic properties," says Yousoo Kim, who led the team. "We have shown that the electronic properties can be manipulated merely by changing the shape of the carbon structure. It will be exciting to see if this discovery could lead to new uses for graphene." ■

Reference

1. Lim, H., Jung, J., Ruoff, R. S. & Kim, Y. Structurally driven one-dimensional electron confinement in sub-5-nm graphene nanowrinkles. *Nature Communications* **6,** 8601 (2015).

PHYSICS

Mind the gap!

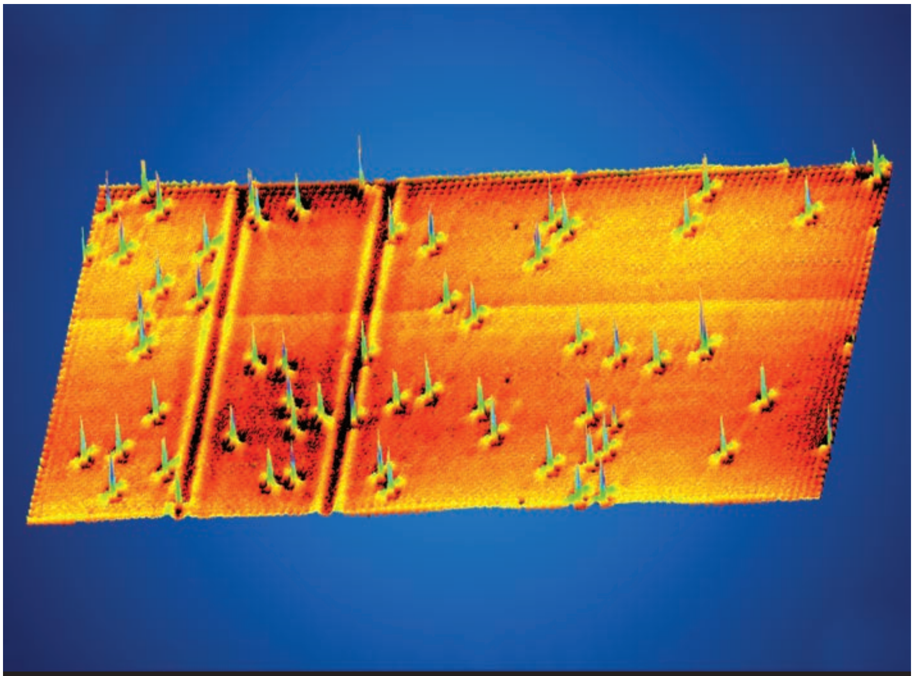
Scanning tunneling microscopy is used to probe electrons in an unconventional superconductor, and uncovers an unexpected energy gap

The properties of electrons around junctions between unconventional superconductors have been directly measured for the first time, opening up a way to explore the unusual behavior of these electrons[1].

When a superconducting material is cooled below its critical temperature, its electrons form bound pairs—known as Cooper pairs—that carry electrical current without resistance. If two superconductors are close to each other, Cooper pairs can move between them via a quantum-mechanical process known as tunneling. This phenomenon has been exploited to create sensitive devices for measuring magnetic fields.

But a growing number of unconventional superconductors have been identified that do not behave according to the prevailing theories of superconductivity, and the nature of Cooper pairs in these materials is poorly understood.

Working as part of an international team, researchers at the RIKEN Center for Emergent Matter Science studied one such unconventional superconductor called iron selenide (FeSe). It contains twin boundaries —fault lines within the crystal that have mirror-image arrangements of atoms on each side. Each



A double twin boundary in iron selenide (seen as parallel grooves in this scanning tunneling microscopy image) along with point-like defects (green peaks).

twin boundary acts as a junction between the neighboring superconducting regions.

The team used scanning tunneling microscopy and spectroscopy to investigate the properties of electrons around a twin boundary at a range of energies and at different locations.

Very close to the boundary, the energy needed to prise apart a Cooper pair—known as the superconducting gap energy—should theoretically be zero. Once separated, the electrons retain some information about their superconducting state and are called quasiparticles.

But the team found that the superconducting gap never diminishes; indeed, the quasiparticle density is lower than expected even 50 nanometers from the boundary, implying that the boundary had an unexpectedly long-range influence. The team conjectures that the twin boundary creates an additional superconducting gap, making it tougher for Cooper pairs to break up and reducing the number of low-energy quasiparticles produced.

This induced superconducting gap existed in only one of two possible forms—a phenomenon called time-reversal symmetry breaking, which is not possible in conventional superconductors. "We found a new superconducting state that has been theoretically predicted but never verified experimentally," says RIKEN team member, Tatsuya Watashige.

The researchers also studied a region where two twin boundaries ran parallel to each other, roughly 34 nanometers apart (see image), and found almost no lowest-energy quasiparticles. "The sandwiched region is effectively protected from low-energy quasiparticles by the induced gaps on both sides," explains another team member, Tetsuo Hanaguri. "We hope that this new playground may host as-yet-unknown emergent phenomena." ■

Reference

1. Watashige, T., Tsutsumi, Y., Hanaguri, T., Kohsaka, Y., Kasahara, S., Furusaki, A., Sigrist, M., Meingast, C., Wolf, T., Löhneysen, H. v. *et al.* Evidence for time-reversal symmetry breaking of the superconducting state near twin-boundary interfaces in FeSe revealed by scanning tunneling spectroscopy. *Physical Review X* **5,** 031022 (2015).

PHYSICS | PRESS RELEASE

Largest ensemble simulation of global weather using real-world data

Researchers explore how to best incorporate real-world data into huge models of the world's weather

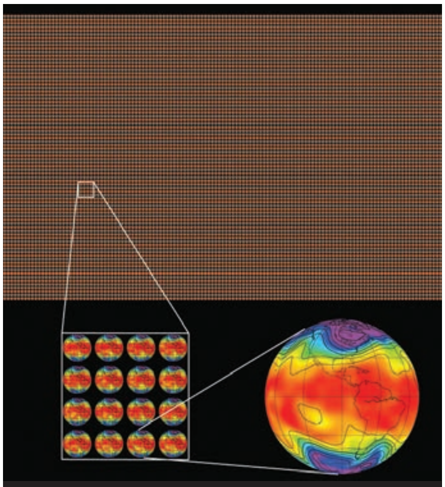
By running simulations on Japan's flagship 10-petaflop K computer, researchers at RIKEN have discovered that observations of weather in distant locations can significantly affect local weather forecasts[1].

When performing numerical weather predictions, it is vital both for the simulation to be accurate and for observation-based, real-world data to be accurately entered into the model. Weather simulations typically involve having the computer conduct a number of simulations based on the current state, and then entering observational data into the simulation to nudge it closer to the actual state.

The problem of incorporating data in the simulation—data assimilation—has become increasingly complex due to the large number of data types currently available, including satellite observations and ground station measurements. Supercomputers today typically spend approximately equal amounts of time running simulations and incorporating real-world data.

Now, with research that could lead to more accurate forecasts, Takemasa Miyoshi, Keiichi Kondo and Koji Terasaki of the RIKEN Advanced Institute for Computational Science have run an enormous global weather simulation. The simulations were run on the K computer—one of the world's largest high-performance computers—using NICAM, a simulation that accurately models the atmosphere. The scientists ran 10,240 simulations of a model of the global atmosphere divided into 112-kilometer sectors (see image). They then used data assimilation and statistical methods to come up with a model closely fitting the real data for the week 1–8 November 2011.

Importantly, the team discovered that observations in distant locations—even up to several thousand kilometers away—may have an impact on the local weather forecast. For



Using the formidable computing power of the K computer, RIKEN scientists ran 10,240 simulations of the world's atmosphere.

instance, data from the Great Lakes region in the United States can affect the weather in Europe. This suggests the need for further research on advanced methods that can make better use of distant observations, as this could lead to improved weather forecasts.

"Forecasting is becoming better thanks to more powerful computers and better observational data from satellites and radars," explains Miyoshi, who led the research team. "We attempted to use a large number of samples using a relatively coarse simulation, and found that it performed quite well, fitting the actual data from the time period we chose."

The team plans to extend their study using even greater computing power. "We are planning to use the power of the K computer's successor, as it develops, to create tools that could be used for better weather forecasting," says Miyoshi.

Reference

1. Miyoshi, T., Kondo, K. & Terasaki, K. Big ensemble data assimilation in numerical weather prediction. *Computer* **48,** 15–21 (2015).

MATERIALS

Magnetic material feels the strain

Stretching a material offers a way of tuning an exotic form of magnetism

A method for controlling magnetic skyrmions through applying a strain to a material has been demonstrated by RIKEN researchers[1]. Such skyrmions are potentially useful for low-power magnetic memories.

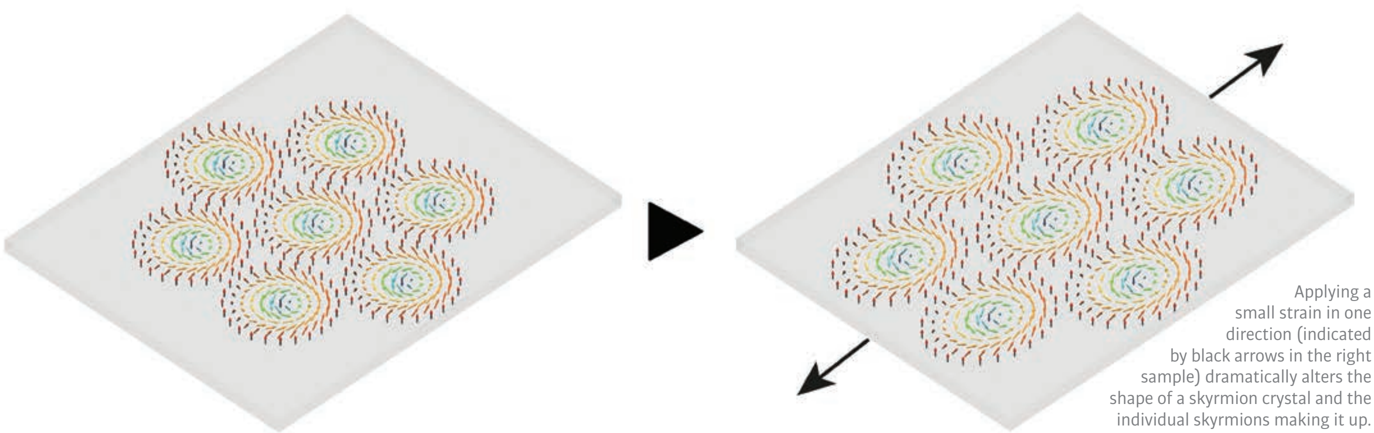
Magnetism occurs in a solid because of an intrinsic property of electrons called spin. This can be visualized as an arrow pointing along the axis about which the electrons rotate. In most materials, the arrows point in random directions, but they are ordered in magnetic materials due to 'spin–spin interactions'. To harness spin for device applications, a technique is needed for controlling this ordering through the application of an external field.

Kiyou Shibata of the University of Tokyo and co-workers at the RIKEN Center for Emergent Matter Science have now demonstrated a mechanical method for controlling the shape of an exotic form of magnetic ordering known as a skyrmion. The distribution of spins in a skyrmion resembles a vortex: the spin points down in the center, the spin in concentric circles about the center is rotated at increasingly large angles with distance from the center, while the spin on the outside points upwards. Skyrmions have been observed both individually and in groups having crystal-like structures, known as skyrmion crystals.

Previously developed methods for controlling skyrmions include applying electric currents and altering the chemical composition of a material. Now, Shibata and his team show that a skyrmion crystal can be tuned by stretching the host material. "This effect can be exploited by using voltage-induced strain in piezoelectric hybrid devices," says Shibata.

The researchers attached both ends of a trimmed iron germanium thin plate to a silicon frame and then thinned the center region of the plate to 150 nanometers. When the temperature was reduced, the iron germanium and silicon contracted at different rates, creating strain in one direction of the sample.

The team created a skyrmion crystal by cooling the sample while applying a magnetic



Applying a small strain in one direction (indicated by black arrows in the right sample) dramatically alters the shape of a skyrmion crystal and the individual skyrmions making it up.

field and imaged it using a technique called Lorentz transmission electron microscopy. In this way, they observed large elongations of both the skyrmion crystal and the individual skyrmions making it up as the sample was cooled from 260 to 94 kelvin (see image).

Magnetic skyrmions arise because of a certain spin–spin interaction. These results reveal that a strain as small as 0.3 per cent can greatly affect this interaction and distort the skyrmion crystal lattice by more than 15 per cent.

"We think that these properties could provide a practical way for manipulating skyrmions and may pave the way for developing devices that use them," says Shibata.

Reference

1. Shibata, K., Iwasaki, J., Kanazawa, N., Aizawa, S., Tanigaki, T., Shirai, M., Nakajima, T., Kubota, M., Kawasaki, M., Park, H. S. *et al.* Large anisotropic deformation of skyrmions in strained crystal. *Nature Nanotechnology* **10,** 589–592 (2015).

BIOLOGY | PRESS RELEASE

Secrets of a rice-killing fungal toxin

Scientists discover how a fungus that destroys rice plants produces a harmful toxin

The enzyme needed by various fungi to synthesize a toxin that harms crops has been discovered by RIKEN scientists[1].

Fungi produce toxins that are not directly involved in their growth, development or reproduction. They often contaminate crops, making them an economic burden for farmers. At least three plant pathogenic fungi produce the toxin tenuazonic acid, which spoils fruits, vegetables, rice and other crops.

Genes for many secondary metabolites produced by microorganisms like fungi are difficult to find because they are silent under laboratory conditions. The RIKEN Center for Sustainable Resource Science team reasoned that a gene associated with responses to environmental stress might be related to tenuazonic acid production in the rice blast fungus *Magnaporthe oryzae* (see image). While wild-type *M. oryzae* did not yield tenuazonic acid, *OSM1* knockout strains produced the acid. The team could also produce tenuazonic acid by culturing wild-type *M. oryzae* with dimethyl sulfoxide.

Having two methods to produce tenuazonic acid in the lab was the key to tracking down the gene responsible for its biosynthesis. DNA microarray analysis of the total RNA extracted under the two conditions that yielded tenuazonic acid revealed that only one gene was expressed significantly more compared to when no tenuazonic acid was produced.

Further tests confirmed that this gene is responsible for tenuazonic acid biosynthesis. Knocking out this gene yielded a strain that could not produce tenuazonic acid, and the researchers renamed the gene *TeA synthetase 1* (TAS1). They then created an *M. oryzae* strain that overexpressed *TAS1*, and, as expected, it produced tenuazonic acid under normal conditions.

The researchers found that TAS1 is a hybrid enzyme containing a non-ribosomal peptide synthetase (NRPS) region followed by a polyketide synthase (PKS) region. "This was very surprising," says Takayuki Motoyama, a member of the team. "It was assumed because of tenuazonic acid's structure that it would be synthesized by a PKS–NRPS hybrid enzyme. In fact, the order of these regions was totally reversed!" While NRPS–PKS hybrid enzymes have been found in bacteria, TAS1 is the first fungal enzyme for a secondary metabolite to be discovered with an NRPS–PKS structure.

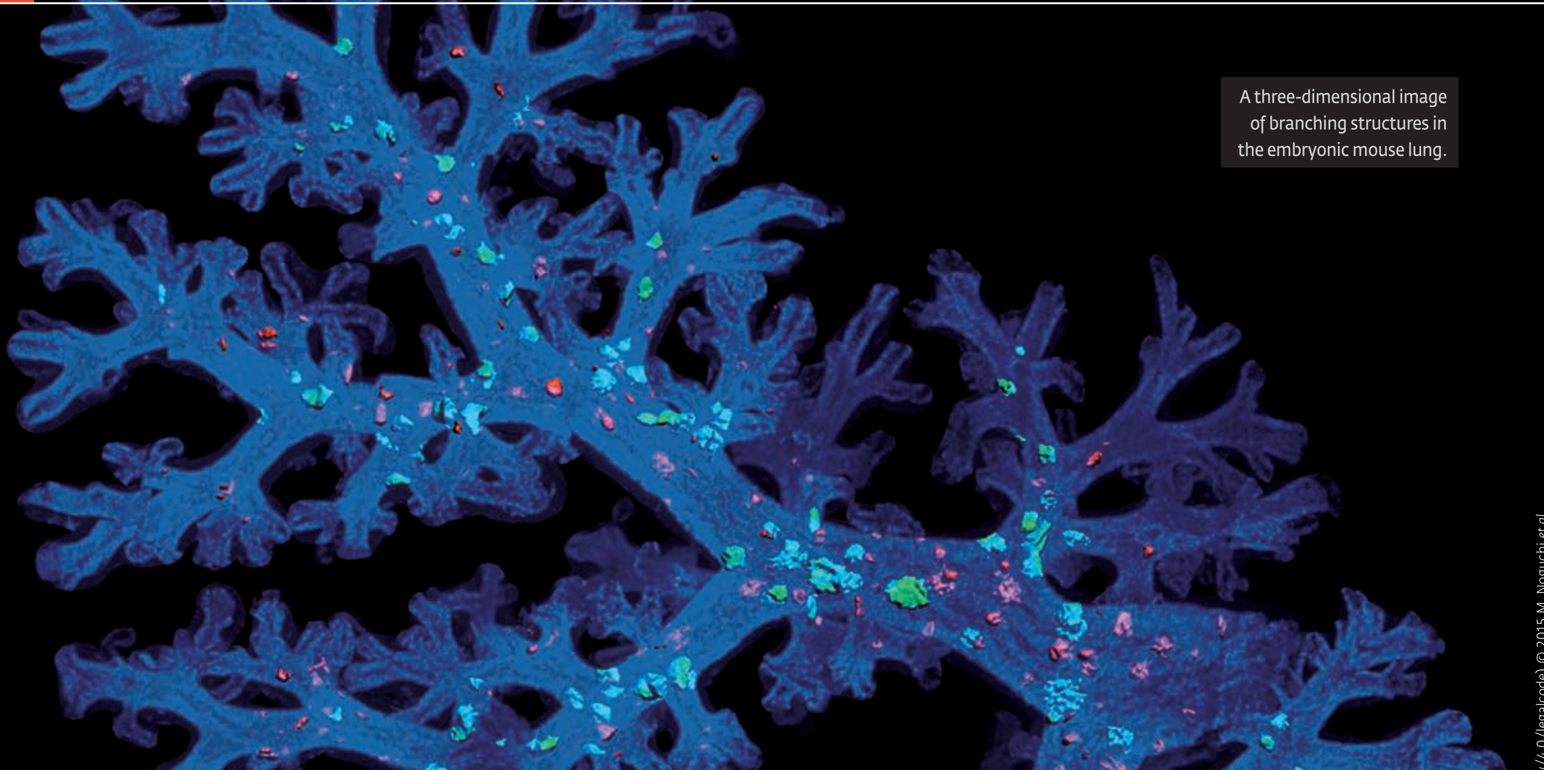
"Now that we know the gene responsible for the biosynthesis of this harmful toxin, further testing might allow us to devise a way to regulate its expression and prevent the spoilage of important crops," notes Motoyama.

While detrimental to crops, tenuazonic acid exhibits antitumor, antibacterial and antiviral properties, and so understanding how the acid is synthesized by TAS1 is an important next step.

Two cells known as appressoria, which the rice blast fungus *Magnaporthe oryzae* uses to infect rice plants.

Reference

1. Yun, C.-S., Motoyama, T. & Osada, H. Biosynthesis of the mycotoxin tenuazonic acid by a fungal NPRS–PKS hybrid enzyme. *Nature Communications* **6,** 8758 (2015).



A three-dimensional image of branching structures in the embryonic mouse lung.

Hiroshi Hamada is director of the RIKEN Center for Developmental Biology Hamada's current research interests are the development of morphological asymmetries in the mouse embryo, such as left–right and anterior–posterior (head–tail) asymmetry. He is also a recipient of the 2014 Keio Medical Science Prize.

Developmental biology

Cultivating collectives of cells

For the past century, developmental biologists have been seeking answers to the same fundamental questions—how does a small, uniform group of cells multiply into the myriad cell types found in living organisms? And how do these cells collectively organize into complex architectures? Advances in stem cell technology have now given them the tools to study these processes in human cells and to engineer tissues and organs that promise to usher in a new era of regenerative medicine.

From a single fertilized cell can grow a complex organism made of trillions of cells. Each cell is characterized by a specific set of physical attributes that defines its role as part of the whole.

Developmental biologists have been studying the processes by which multicellular organisms grow and develop for about a 100 years. They have identified many of the molecules and genes involved in differentiating cells into distinct types, from neurons to cardiac muscle cells. This has given them the power to control the fates of individual cells.

But it is much more challenging to create collectives of cells that generate coherent thoughts and pump to the same heartbeat. How does a homogeneous population divide and differentiate into distinct organs and form an integrated organism? How are the fates of neighboring cells intertwined? To understand these processes, developmental biologists must learn the language cells use to communicate between themselves.

Researchers at the RIKEN Center for Developmental Biology (CDB) have begun to speak this language. They are using their skills to understand how the body forms during development. They then apply their knowledge to culture artificial organs, which are set to transform regenerative medicine.

Cell talk

Early in an embryo's life, it forms into a group of cells known as the germ layer. This collection of cells consists of an outer (ectoderm), middle (mesoderm) and inner (endoderm) layer; these layers develop into all the organs and tissues in an animal. In the early 1980s, two researchers in the United States were studying the section of the ectoderm in grasshopper embryos that forms the nervous system. They noticed that only a fifth of these cells grew into neuronal precursor cells, while the rest became either supporting cells or died. By selectively zapping individual ectodermal cells with a laser beam, they discovered that this selection process results from molecular communication between neighboring cells in a cluster.

Around the same time, Masatoshi Takeichi at the CDB discovered a novel molecule controlling the communication between cells. He found that the cell-surface adhesion molecule cadherin, in the presence of calcium, facilitates the selective binding of similar cells to form and maintain tissues

Developmental biologists have been studying the processes by which multicellular organisms grow and develop for about a 100 years. They have identified many of the molecules and genes involved in differentiating cells into distinct types, from neurons to cardiac muscle cells.

and organs—much like a gluing agent. Over the past three decades, more than 100 types of cadherin have been identified in various embryonic and adult tissues of simple and complex organisms, including in the segregation and sorting of different types of motor neurons during chick spinal cord development. Most recently, Takeichi's team has determined the role of a specific class of cadherin in coordinating axon growth to ensure the proper neuronal wiring of embryonic mouse brains[1].

There is still a lot to learn about cell fate during development, but even more needs to be understood about how mixtures of different types of cells organize into robust structures, patterns and ultimately organs. This process is guided by mechanical forces that stretch and compress cells into the right size and shape to produce functional tissue. Thus, sheets of cells held together by adhesion molecules fold or curl into complex structures. The neural tube is one such structure, which forms from an epithelial sheet called the neural plate that bends in, rolls up and pinches off to form an enclosed cylinder. Similar processes are involved in widening and lengthening the

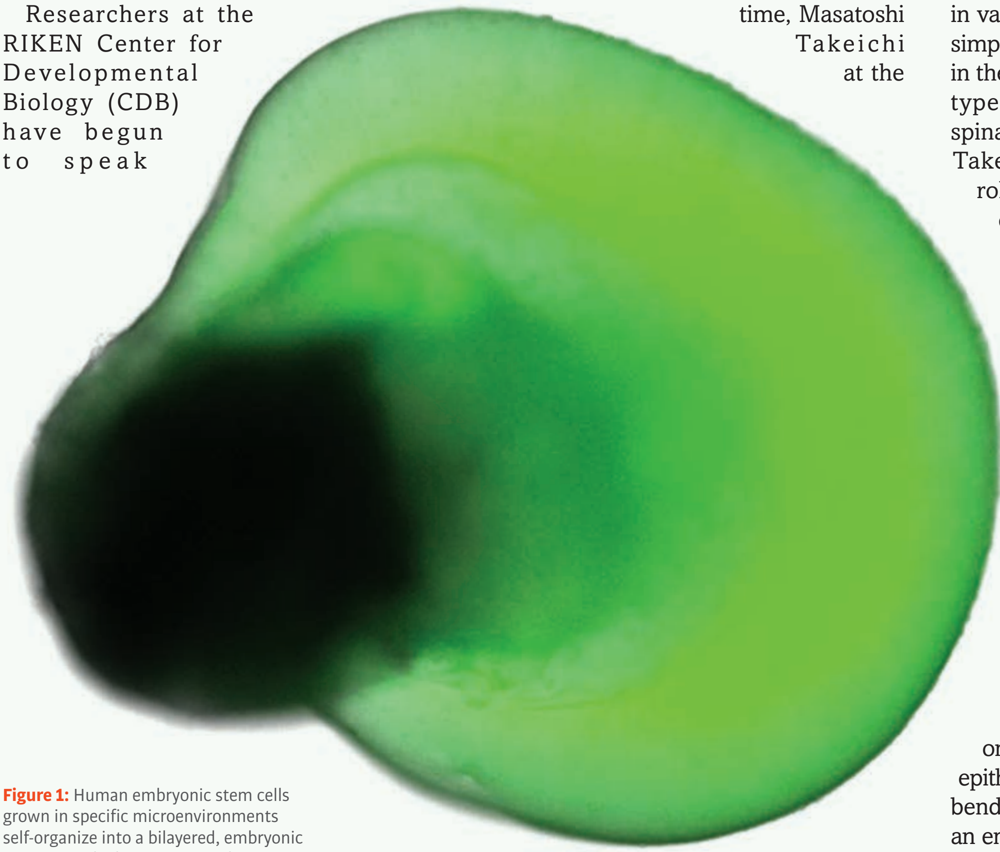


Figure 1: Human embryonic stem cells grown in specific microenvironments self-organize into a bilayered, embryonic optic cup, which gives rise to the retina.

windpipe, which Shigeo Hayashi at the CDB is studying in the fruit fly respiratory system.

The biochemical cues used to transmit these mechanical signals between cells are only just beginning to be characterized. Among other examples, Shigenobu Yonemura's laboratory (now reorganized into the RIKEN Center for Life Science Technologies) found in 2010 that a molecule that binds to the sticky protein cadherin changes shape when pulled in a certain direction by adjacent cells. These molecules thus help to maintain the integrity of tissues.

Improvements in theoretical modeling and microscopy techniques will help visualize these processes more clearly, which some groups at the CDB are developing together with researchers at the RIKEN Quantitative Biology Center. Mitsuru Morimoto's laboratory, for example, has refined techniques for observing the developing mouse lung in three dimensions of space and a fourth dimension time (see image on page 24)[2].

Copying embryonic development

Some of the earliest developmental biology experiments from the 1920s used salamanders, sea squirts and frogs as early models to understand embryonic development. Major breakthroughs in the manipulation of gene expression then refined our understanding of development in a handful of model organisms, such as the mouse, zebrafish, fruit fly and roundworm. Only in the late 1990s did we find the means to study early development in humans, initially by deriving stem cell lines directly from the human embryo. A decade later, Shinya Yamanaka at Kyoto University developed a technique to induce adult cells into a pluripotent state with the potential to become any cell type in the body. And in the last few years, quick and efficient genome editing tools, such as CRISPR-Cas9, have made it easy to probe the effects of genome engineering in almost any organism, including human stem cells.

But if these cells are considered the magic seeds for growing artificial human organs, many of the breeders that have mastered the skills to grow them are at the CDB. They have applied their deep knowledge of embryonic development to the generation of three-dimensional organs in a dish, more commonly known as organoids.

Yoshiki Sasai was one of the first researchers in the world to cultivate embryonic stem cells into organoids, including an optic cup[3], the outer tissue of the brain and an elementary pituitary gland. The general principle of his method was to treat embryonic stem cells as they would be treated in an actual embryo. Another key to controlling the system, he found, was to let it control itself. Embryonic stem cells grown in specific microenvironments autonomously fold into the rounded shape of a rudimentary, bilayered optic cup.

Yoshiki Sasai was one of the first researchers in the world to cultivate embryonic stem cells into organoids, including an optic cup, the outer tissue of the brain and an elementary pituitary gland.

Sasai's achievements have been succeeded by his former colleagues, including Mototsugu Eiraku and Keiko Muguruma. Eiraku has generated a three-dimensional retina, and improved on the retinal cell differentiation process by inducing human embryonic stem cells to self-organize into more specialized optic cups. These optic cups contain an interstitial layer of cells between their inner and outer layers called the ciliary margin (Fig. 1)[4]. And Mugurama has recently grown the cerebellum of a baby in its first trimester from human embryonic stem cells.

While their work remains experimental, a colleague at the CDB, Masayo Takahashi, has grown sheets of retinal epithelial cells to treat a degenerative eye disease. The retinal pigment epithelium, which nourishes the retina, is formed from the outer layer of the optic cup in an embryo. Takahashi grew the sheets of epithelial cells from iPS cells generated from patients with age-related macular degeneration. In 2014, she transplanted the cell sheets back into a patient's eye in the first clinical study of its kind. One year since the surgery, the patient's eye has shown no sign of tumor growth and their vision has stabilized.

Other laboratories involved in organ growth and repair include Takashi Tsuji's laboratory bioengineering teeth and hair and Morimoto's group reconstructing damaged lung tissue. The CDB is also in the process of hiring a member from the first team to grow a mini kidney organoid. The kidney is notoriously difficult to regenerate because it emerges late in embryonic development and contains more than 20 distinct cell types, yet it is of high medical value.

Stem cell technology for organ regeneration and rehabilitation is set to transform the field of medicine, and CDB researchers are working at the frontline. ■

References

1. Hayashi, S., Inoue, Y., Kiyonari, H., Abe, T., Misaki, K., Moriguchi, H., Tanaka, Y. & Takeichi, M. Protocadherin-17 mediates collective axon extension by recruiting actin regulator complexes to interaxonal contacts. *Developmental Cell* **30,** 673–687 (2014).
2. Noguchi, M., Sumiyama, K. & Morimoto, M. Directed migration of pulmonary neuroendocrine cells toward airway branches organizes the stereotypic location of neuroepithelial bodies. *Cell Reports* **13,** 2679–2686 (2015).
3. Eiraku, M., Takata, N., Ishibashi, H., Kawada, M., Sakakura, E., Okuda, S., Sekiguchi, K., Adachi, T. & Sasai, Y. Self-organizing optic-cup morphogenesis in three-dimensional culture. *Nature* **472,** 51–56 (2011).
4. Kuwahara, A., Ozone, C., Nakano, T., Saito, K., Eiraku, M. & Sasai, Y. Generation of a ciliary margin-like stem cell niche from self-organizing human retinal tissue. *Nature Communications* **6,** 6286 (2015).

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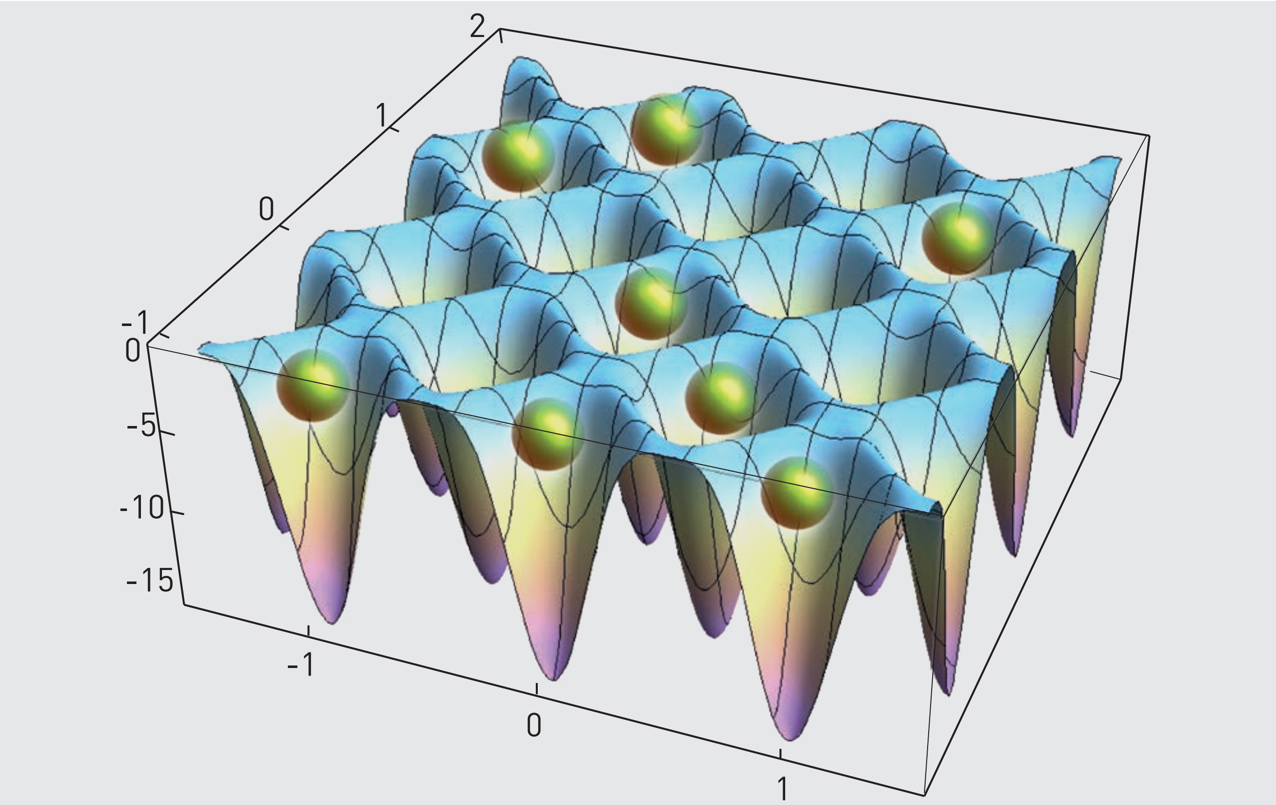


An optical lattice generated by intersecting laser beams can trap ultracold atoms and ions in its troughs.

PHYSICS

A sensitive approach to atom counting

Measurements of scattered photons can be used to detect the number of atoms trapped in the troughs of an optical lattice

A new technique for counting atoms that overcomes a fundamental limitation on resolution and does not disturb the atoms being measured has been theoretically proposed by researchers at RIKEN[1].

Combining multiple intense laser beams can create a two-dimensional lattice of electric-field peaks and troughs, forming a pattern resembling an egg box (see image). And like eggs in an egg box, atoms or ions that have been cooled to an effective temperature in the microkelvin regime can become trapped in the minima of this optical lattice.

This creates what is known as a quantum gas, which is an ideal test bed for investigating the predictions of quantum theory. The properties of the gas can be controlled by varying the wavelength or the intensity of the laser light, opening the door to generating a wide range of quantum-mechanical states that are not found in naturally occurring materials. For researchers studying quantum gases, it is crucial to be able to determine how many atoms, if any, are trapped at each site in an optical lattice.

Conventional imaging methods, such as microscopy, are incapable of imaging objects at the atomic scale, whereas alternative techniques that use intense light to probe each point in the lattice can alter the quantum gas, destroying the atomic state that was to be investigated. Now, Yuto Ashida and Masahito Ueda from the RIKEN Center for Emergent Matter Science and the University of Tokyo have theoretically proposed a non-destructive method for detecting atoms in an optical lattice with single-site resolution.

"In all optical measurements, the wavelength of light imposes a fundamental limit on detection—two objects within a wavelength of each other cannot be resolved," explains Ueda. "The physics behind this so-called diffraction limit is the fact that photons scattered from two point sources that lie within a wavelength tend to interfere, which smears out the peak positions of the image at the detector."

The pair's approach involves building a statistical picture of how far photons are deflected when they are scattered by the atoms. "We use quantum measurement theory that automatically accounts for the entire interference pattern, rather than just the peak position and its width," says Ueda.

"This enables us to extract unbiased positional information of atoms. Furthermore, it can distinguish atomic configurations even if they reside within a wavelength." Ashida and Ueda are confident that the same concept can be applied to conventional microscopy and hope to extend their idea to the super-resolution imaging of biological objects.

Reference

1. Ashida, Y. & Ueda, M. Diffraction-unlimited position measurement of ultracold atoms in an optical lattice. *Physical Review Letters* **115,** 095301 (2015).

PHYSICS | PRESS RELEASE

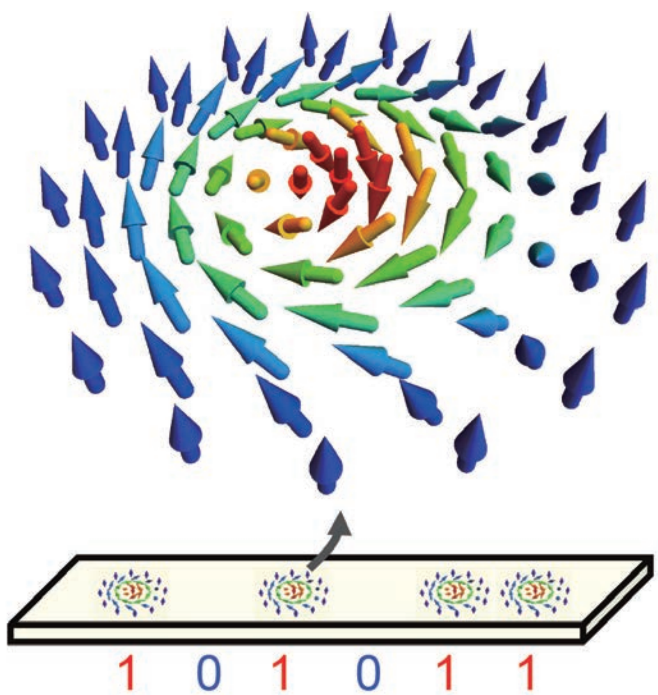
Just a touch of skyrmions

A new way of creating and destroying skyrmions by simply applying a force could lead to low-power memory devices

Recording methods used since antiquity such as writing are based on mechanical energy, but they are now giving way to memory devices that use electrical energy to manipulate electrons. Scientists at RIKEN may be about to wind back time, as they have discovered a way to record information that involves using mechanical energy to manipulate tiny nanoscale magnetic vortices known as skyrmions, which form on the surfaces of magnetic materials (see image)[1].

Because of their small size and relative stability, skyrmions are widely anticipated to become the basis for new high-density memory devices. So far, however, skyrmions have proved to be difficult to create, delete and move. Consequently, skyrmion-based devices are not yet competitive with other high-tech devices based on electron spin.

Describing how the research started, the first author of the study, Yoichi Nii of the RIKEN Center for Emergent Matter Science, says: "We began from the simple question of whether it would be practical to turn skyrmions on and off with mechanical force, and wondered how much force would be required. We imagined it would be substantial."



Magnetic skyrmions that can be created and deleted by applying small mechanical forces could form the basis of next-generation magnetic memories.

The group explored the use of a specially designed stress probe that can apply mechanical stress to the surface of manganese silicide, a 'chiral magnetic' material known to host skyrmions. To their surprise, they found that when the probe was cooled to very low temperatures, the force needed to create and destroy skyrmions was quite low—several tens of nanonewtons per skyrmion. The corresponding stress is comparable to that applied to the tip of a conventional pencil during writing. The researchers found that skyrmions could be created by applying a force perpendicular to the magnetic field and could be turned off by applying a force parallel to the field. Thus, skyrmions can be turned on and off mechanically.

"This means that we may be able to fabricate devices in which skyrmions are created and deleted by a small mechanical force," says Yoshihiro Iwasa, the team leader. "This could be an inexpensive and low-energy-consuming way to create new low-cost memory devices and open the road to skyrmionics."

One drawback of the current method is that the magnet has to be cooled to very low temperatures for the system to work. According to Nii, the team plans to test a variety of materials to try to identify those capable of hosting skyrmions that can be mechanically manipulated at higher temperatures. ■

Reference

1. Nii, Y., Nakajima, T., Kikkawa, A., Yamasaki, Y., Ohishi, K., Suzuki, J., Taguchi, Y., Arima, T., Tokura, Y. & Iwasa, Y. Uniaxial stress control of skyrmion phase. *Nature Communications* **6,** 8539 (2015).

PHYSICS

How a star turns inside out

Simulations of a supernova suggest that density variations inside a star help propel heavy elements from its core

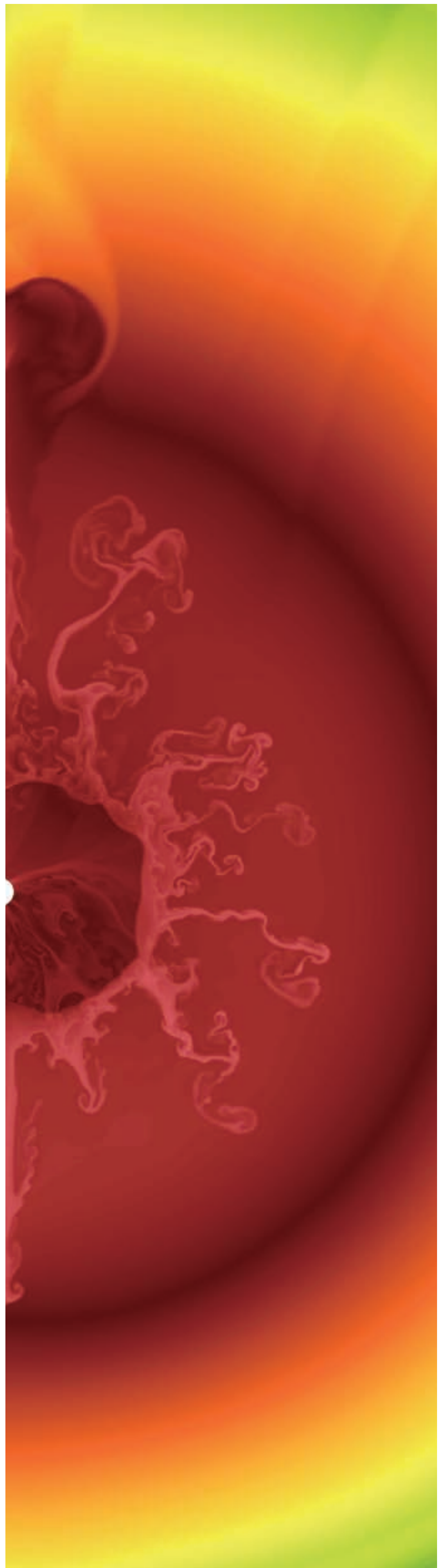
When the core of a massive star collapses under its own gravity, it can trigger a supernova—an incredibly energetic explosion that flings the star's content far out into space. Detailed simulations now suggest that density variations between layers inside the star could help accelerate that core material to remarkable speeds[1].

A team of researchers led by Shigehiro Nagataki of the RIKEN Astrophysical Big Bang Laboratory based their simulation on supernova SN1987A, which formed from a blue supergiant star that exploded in the Large Magellanic Cloud, a nearby galaxy. Material from the star's core, including clumps of a radioactive isotope of nickel (^{56}Ni), streaked out in long 'fingers'. Up to 17 per cent of this nickel moves faster than 3,000 kilometers per second—similar to the speeds of hydrogen and helium blown from the star's outer layers. Astronomers have struggled to explain how this core material could exit the star so quickly.

One possibility is that as the exploding core pushed relatively low-density material into the star's outer layers, it created a form of turbulence (known as Rayleigh–Taylor instability) similar to the mushroom cloud of gas and ash from a volcanic eruption. But the precise origin and location of this instability have remained a mystery.

Nagataki's team's simulation now offers an answer. They based their model on a blue supergiant, which is more than 16 times the mass of our own Sun. It has a nickel core surrounded by successive onion-like layers that are rich in sulphur, silicon, oxygen and carbon, helium and finally hydrogen. Simulations performed for several different types of supernova explosions revealed the conditions that most closely matched astronomical observations (see image).

The simulation produced high-speed nickel clumps when there were density fluctuations of 25 per cent or more at the interfaces between the helium and carbon–oxygen layers, and between the helium and hydrogen layers. The simulated explosion was also asymmetric, with more material funneled into jets on opposite



A simulation of supernova SN1987A suggests that lower-density material can form tendrils that push into the star's outer layers as it explodes from the core (center left).

sides of the star, and with one jet more powerful than the other. This model is the most accurate reproduction of SN1987A to date, says Nagataki.

The underlying density fluctuations could arise from convection currents inside the star, says Nagataki. "As for the asymmetric and jet-like explosion," he adds, "it can be produced at the center of the supernova."

The simulation successfully reproduces the first few hours after the birth of SN1987A. The team now hopes to extend their model to cover the entire 28-year lifetime of the supernova.

Reference

1. Mao, J., Ono, M., Nagataki, S., Hashimoto, M.-a., Ito, H., Matsumoto, J., Dainotti, M. G. & Lee, S.-H. Matter mixing in core-collapse supernova ejecta: Large density perturbations in the progenitor star? *The Astrophysical Journal* **808,** 164 (2015).

BIOLOGY | PRESS RELEASE

Mouse model gets the blues

Mice with defective mitochondria show similar symptoms of depression as humans, implicating a previously unsuspected region of the brain

Mice with a genetic mutation that leads to dysfunction of mitochondria—the 'powerhouses' of cells—exhibit periodic episodes of depression-like behavior resembling those in humans, RIKEN scientists have found[1]. They have uncovered a link between depression and a brain region not previously tied to depression.

The study was motivated by the lack of animal models that accurately reproduce depressive episodes in humans. Previous studies had linked mitochondrial diseases to depression. For example, some patients with depressive symptoms had been found to harbor problems with mitochondrial DNA.

Takaoki Kasahara of the RIKEN Brain Science Institute and co-workers decided to investigate where this was happening by experimenting on a mouse strain with a mutation in a gene known to be involved in the replication of mitochondrial DNA.

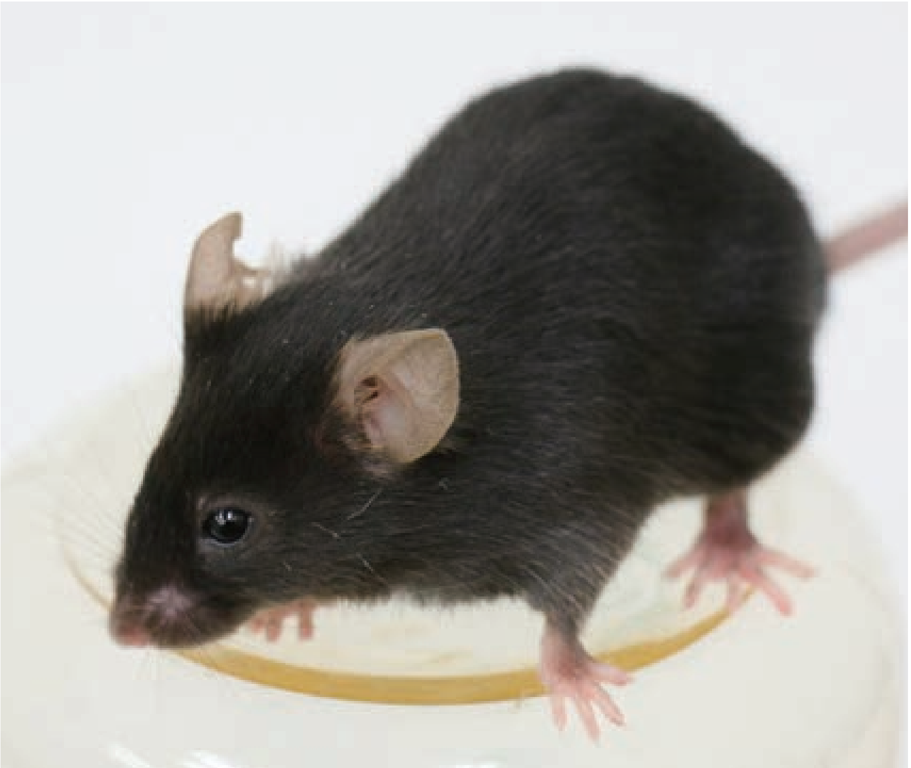
The researchers discovered that, similarly to human patients with mitochondrial diseases, the mice underwent episodes in which they expressed the same signs and symptoms as those of major depressive bouts in humans.

"We were surprised to find that many of the female mutant mice showed symptoms similar to human depression patients," says Kasahara. "During the episodes, the mice would run on their running wheels less extensively, showing they had a lack of pleasure-seeking behavior, a core feature of depression."

The episodes tended to occur about every six months and lasted two or three weeks. They were mitigated when the mice were given a common antidepressant drug. The affected mice had higher levels of corticosterone—an equivalent of cortisol in humans, which is often elevated in depressive patients.

During the episodes, the mice gained weight, ran slower and were more fatigued, all of which are symptoms of depression in humans.

The researchers then investigated which part of the brain was affected by the mitochondrial abnormalities. They found that the paraventricular thalamus—a part of the brain not previously linked to



Mice with a defective gene that leads to dysfunction of mitochondria are found to exhibit similar depressive episodes as depressed humans.

depression—had a particularly high ratio of deleted mitochondrial DNA.

The scientists found similar abnormalities in the paraventricular thalamus in brain slices from two deceased patients who had suffered from a mitochondrial disease coupled with mood symptoms. To test the association, they blocked the transmission of signals from the paraventricular thalamus to other parts of the brain in mice and found that they exhibited similar episodes.

"We are excited about this finding because it could lead to new therapies for depression, which takes a major health toll on society," says Tadafumi Kato, who led the team. "Furthermore, this may represent a new mechanism for the onset of depressive episodes."

Reference

1. Kasahara, T., Takata, A., Kato, T. M., Kubota-Sakashita, M., Sawada, T., Kakita, A., Mizukami, H., Kaneda, D., Ozawa, K. & Kato, T. Depression-like episodes in mice harboring mtDNA deletions in paraventricular thalamus. *Molecular Psychiatry* **21,** 39–48 (2016).

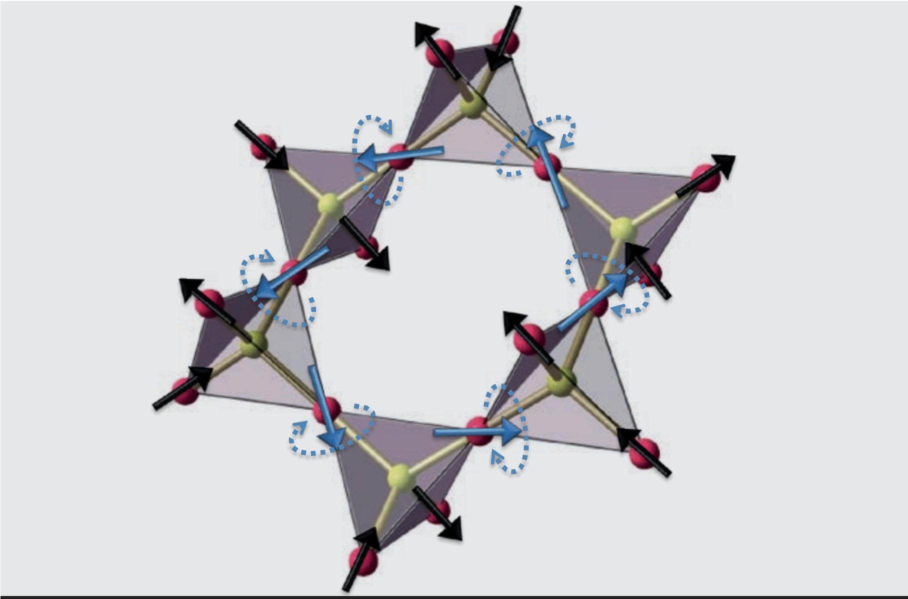
PHYSICS

Melting of frozen frustrations

Computations reveal how quantum interactions can break a deadlock in magnetic spin ice oxides

Physicists have long been seeking to uncover a grand unified theory in which the three non-gravitational forces—the electromagnetic force and the strong and weak nuclear forces—merge into a single force at high temperatures. Such a theory is seen as a critical stepping stone to realizing a 'theory of everything' that combines all four forces. Some grand unified theories that have been proposed predict the existence of magnetic monopoles—the magnetic equivalent of electric charges—in certain crystals.

In the crystals of some oxygen-containing compounds, electron spins are arranged at the edges of the tetrahedrons that make up the crystal structure (see image). In the absence of an external magnetic field, these materials should be non-magnetic, with the same number of spins pointing in each direction. In a crystal, there are endless configurations for achieving this. At low temperatures, spins do not have enough energy to rearrange themselves, and thus the system is 'frozen' into one of these arrangements. These materials are referred to as a spin ice, in analogy to water ice, which is a random arrangement of water molecules.



In spin ice crystals, the magnetic spins of electrons (black and blue arrows) make it difficult for the system to reach its lowest energy state. Quantum interactions can cause spins to flip and lead to ring-like, aligned arrangements of the spins (blue arrows).

Now, Shigeki Onoda and Yasuyuki Kato from the RIKEN Center for Emergent Matter Science have performed calculations to investigate how, at low temperatures, quantum effects in these materials can cause them to 'melt'[1]. Their findings highlight the importance of quantum physics in helping systems to reach favorable energy states. While, according to classical physics, the spins in a spin ice should be frozen at low temperatures, quantum effects allow the spins to interact with each other. "The quantum nature of spins allows for exchanging nearest-neighbor spins," explains Onoda. Such a system is thus termed a quantum spin ice.

By performing computer calculations, the researchers studied how at low temperatures these quantum interactions cause the quantum spin ice to melt through flipping of spins. Through these quantum effects, the spins can align (blue spins in image) and can collectively change their orientation. These collective changes of spin patterns can travel through the crystal in a similar way to particles of light, and are thus dubbed 'photons'.

The next task is to experimentally verify these theoretical predictions, explains Onoda. "We are working on directly relevant models to experimental systems in order to propose experimental observations of quantum spin ice photons and provide theoretical predictions.” This would bring scientists a step closer to uncovering how photons and magnetic monopoles emerge spontaneously in materials. ■

Reference

1. Kato, K. & Onoda, S. Numerical evidence of quantum melting of spin ice: Quantum-to-classical crossover. *Physical Review Letters* **115,** 077202 (2015).

PHYSICS

Attosecond glimpses into electron stripping

Measurements using ultrashort laser pulses show that ions take time to ‘settle’ after being stripped of an electron

Experiments with ultrafast laser pulses reveal that simply removing an electron from a hydrogen molecule does not complete the full ionization process. Rather, there is a subsequent ‘settling’ process that occurs over a much longer time scale than previously thought, a RIKEN study finds[1].

When it comes to molecular ions, they don’t come any simpler than a molecular hydrogen ion (H_2^+). It consists of just two protons and one electron—remove any one of these three components and you are left with something less than a molecular ion. This simplicity has made molecular hydrogen ions very attractive systems for physicists wanting to explore the dynamics of ionization—the process in which one or more electrons are stripped from an atom or molecule.

The recent development of lasers capable of generating incredibly short pulses that last for several attoseconds (10^{-18} second) has enabled scientists to probe molecular processes that occur on femtosecond (10^{-15} second) time scales, such as ionization.

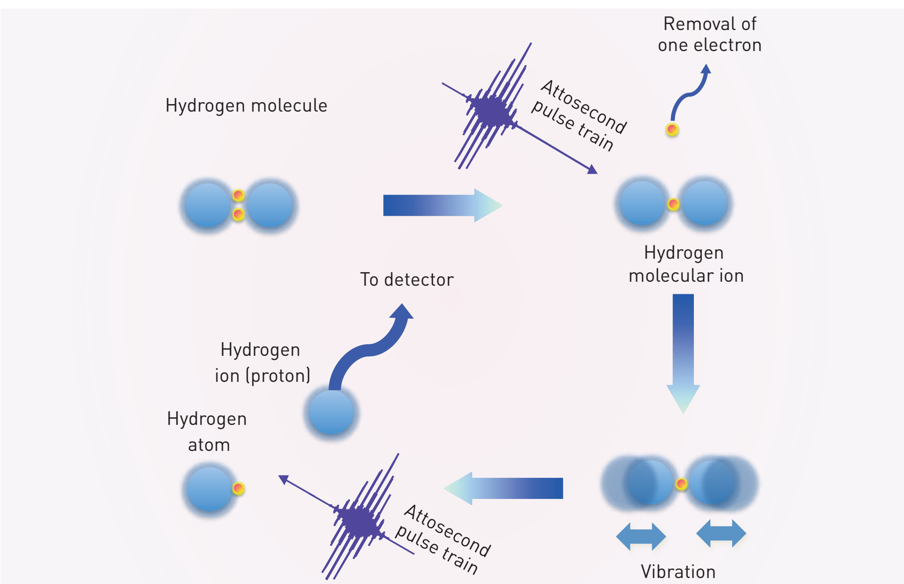
Now, Yasuo Nabekawa and his colleagues at the RIKEN Center for Advanced Photonics and the University of Tokyo have used such lasers to determine what happens when an attosecond pulse train removes an electron from a hydrogen molecule. What they discovered overturns a common assumption that scientists have been employing for decades.

The researchers first prepared a hydrogen molecular ion by using a ‘pump’ pulse from an attosecond laser to eject an electron from a neutral hydrogen molecule. This process set the molecular ion vibrating. The team then used a ‘probe’ attosecond pulse to split the vibrating molecular ion into two parts—a hydrogen atom (a proton and an electron) and a hydrogen ion (a proton), which was observed at a detector (see image).

The measurements revealed that after an electron is ripped from a hydrogen molecule—a process that is thought to take about 0.1 femtoseconds—an approximately one-femtosecond settling time occurs, during which a ‘vibrational wave packet’ is created. The complete ionization process finishes after the settling time of the wave packet.

Previously, scientists had invoked the so-called Franck–Condon principle, which essentially predicts that the wave packet will be spontaneously produced after an electron has been removed. “It used to be believed that all the wave functions were instantaneously and simultaneously created at the time of ionization based on the Franck–Condon principle,” explains Nabekawa. “Our observation clearly goes against this received wisdom.”

In the future, the team intends to use their high-intensity attosecond lasers to manipulate reactions between different chemical species. ■



By firing two successive attosecond pulses (purple waves) at a hydrogen molecule (top left corner; blue spheres are protons and orange spheres are electrons), RIKEN researchers explored the dynamics of ionization of a hydrogen molecular ion.

Reference

1. Nabekawa, Y., Furukawa, Y., Okino, T., Eilanlou, A. A., Takahashi, E. J., Yamanouchi, K. & Midorikawa, K. Settling time of a vibrational wavepacket in ionization. *Nature Communications* **6,** 8197 (2015).

CHEMISTRY

Building better bilayers

A strategy for generating stable lipid bilayers could simplify the study of biologically important membrane proteins

An approach for constructing artificial membranes that promises to make proteins in cell membranes easier to study has been developed by a team of RIKEN researchers[1].

Roughly 25 to 30 per cent of all human proteins reside in cellular membranes, where they help cells respond to changing conditions by relaying information from the outside environment to the interior of the cell. These membrane proteins are critical targets for treating diseases.

It is vital to know the structures of proteins when exploring their biological functions. The structures of membrane proteins can be deduced by embedding them in double-layer slabs of phospholipids known as bicelles, which mimic sections of the cell membrane. These bicelles are then analyzed using a technique called nuclear magnetic resonance spectroscopy. In this technique, the proteins under investigation are exposed to a magnetic field that causes them to spontaneously align, enabling detailed structural analysis.

However, generating robust bicelles is problematic. "Conventional bicelles only attain optimal alignment under limited conditions in terms of temperature, pH and so on," says Yasuhiro Ishida of the RIKEN Center for Emergent Matter Science, who led the study. He and his team set out to design a simple strategy for building highly stable bicelles.

Stabilization is necessary since one end of a phospholipid preferentially interacts with water, whereas its other end is repelled by water, resulting in the formation of sandwich-like bilayers. Chemicals known as surfactants are generally used to cap the rims of the bicelles.

Ishida's team improved on this approach by using special surfactants that can assemble themselves into multimolecular polymers (see image). These surfactants bind much more tightly to the bilayer rims than individual surfactant molecules. Consequently, the resulting bicelles exhibited remarkable stability and a capacity for robust magnetically induced alignment over a wide temperature range—from room temperature to more than 90 degrees Celsius.

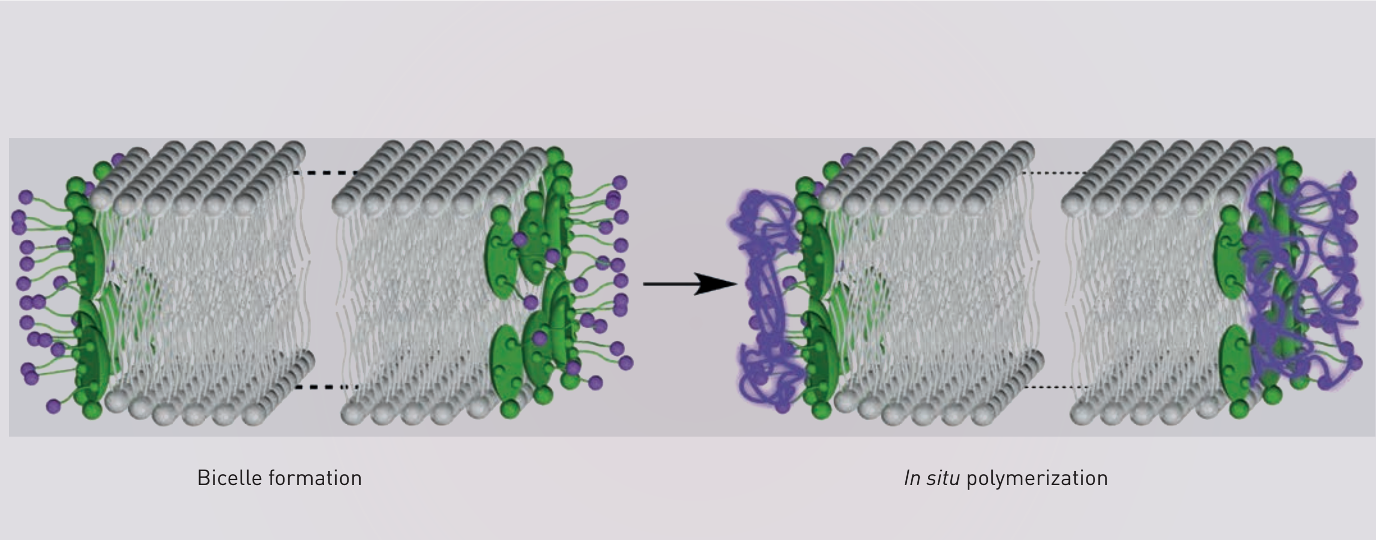
"Other research groups have taken rather complicated approaches where the stabilization effects are not satisfactory," says Ishida. "This work demonstrates that a very simple approach based on polymerization works highly efficiently."

This remarkable temperature stability means that these bicelles could be used to study membrane proteins that are normally active at high temperatures. The researchers are now working to refine their approach so that it performs equally well at near-freezing temperatures.

Ishida also sees potential applications for experimentally modeling cellular processes. "Our bicelle systems could be useful as a simple and easy-to-handle model of biological membranes," he says.

Reference

1. Matsui, R., Ohtani, M., Yamada, K., Hikima, T., Takata, M., Nakamura, T., Koshino, H., Ishida, Y. & Aida, T. Chemically locked bicelles with high thermal and kinetic stability. *Angewandte Chemie International Edition* **54,** 13284–13288 (2015).



The formation of bicelles (left) is stabilized by polymerization (right) of the surfactant molecules (green) that flank the phospholipid bilayer (gray).

Earth-friendly pesticides

Yutaka Arimoto has developed 'SaFE' pesticides from common household products

A treatment against the tomato yellow leaf curl virus prevents transmitters of the virus, the silverleaf whitefly, from pairing on tomato plant leaves.

The fungus spreads slowly, hibernating through winter in the dried and diseased branches of citrus trees. Come spring, it disperses its spores in raindrops that fall on budding leaves and branches. The pathogen then creeps to the fruit stems, where it waits until fall's harvest to spread a shadow of rot over the fruit.

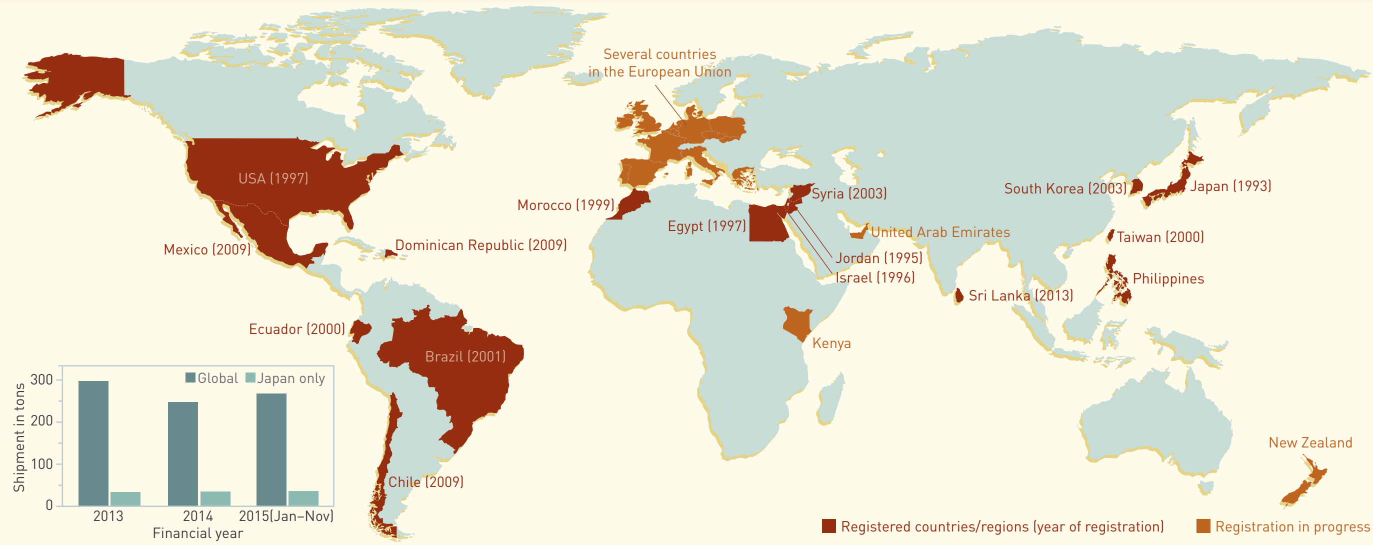
In the early 1970s, Yutaka Arimoto, then a young researcher at RIKEN, wondered why the invasion of the citrus tree fungus *Diaporthe citri* followed the seasons. Perhaps that cycle could be used to defeat it, he thought. Having grown up on a farm, Arimoto had seen firsthand the damage pests and diseases cause to crops, but he also knew that many pesticides used to prevent them were later taken out of use. "Unexpected things can happen, and there is never a guarantee that current testing methods are infallible," he says. "No chemical is 100 per cent safe, but by selecting compounds that people have been consuming for a long time without adverse effects, we assume that there is a very small chance of unexpected problems arising."

Arimoto's resolution to search for environmentally friendly products with antifungal properties launched him into a career developing commercial pesticides from edible chemicals, which he refers to as SaFE (Safe and Friendly to the Environment) pesticides. But the path has not always been easy.

"When doing research, you inevitably run into walls that prevent further progress," says Arimoto, who now heads his own laboratory at the RIKEN Innovation Center. "But it can be exhilarating when you finally find a small crack in the wall, expand the crack and squeeze through the wall."

Today, a growing community of organic farmers is creating a demand for agricultural products that ensure the productivity, health and safety of soils, plants, animals and people.

Global distribution of Kaligreen



In the kitchen

When considering the seasonal advance of *Diaporthe citri*, Arimoto wondered whether antifungal substances produced in citrus tree stems dwindled when the citrus was harvested, making it vulnerable to attack. His hunch proved right: he discovered that a yellowish compound called hesperidin in the stem, when mixed with other common household products such as potassium bicarbonate and sodium bicarbonate, killed the fungus. Further experiments on other pathogens produced similar fungicidal results, even—much to Arimoto's surprise—when the mixtures did not contain hesperidin.

The mixtures contained sodium bicarbonate, more commonly known as baking powder and a standard treatment for heartburn and indigestion. Its close relative, potassium bicarbonate, is also a popular food additive in fizzy drinks, chocolate and canned milk. "It's safe to say that it is very unlikely that compounds that have been approved for use in these ways will lead to environmental problems," Arimoto comments.

Solutions of sodium and potassium bicarbonates turned out to be especially good at protecting against powdery mildew, a fungal disease that affects wheat, barley and grapes, among other plants, and can decimate farmers' yields by almost half.

In 1982, after several years of testing and field trials, Arimoto registered his first sprayable pesticide containing sodium bicarbonate, branded Noslan wettable powder. But just as the team was about to launch their new product on the market, disaster struck. "Harmful toxic effects were reported in strawberries and we had to halt development," he says. Twelve years had passed since Arimoto began investigating compounds for use in agriculture, and he was yet to find a success.

Selling pesticides

Undeterred, Arimoto looked for ways to prevent the sodium bicarbonate from crystallizing on plant leaves. Eventually, he discovered an ingredient that could encapsulate the sodium bicarbonate in higher doses, so that only a tenth of the original solution needed to be sprayed on plants. The surfactant he identified is also a common food emulsifier.

With the original Noslan research group disbanded, Arimoto initiated discussions with a company manufacturing potassium bicarbonate. In 1993, Toagosei Co., Ltd launched the product Kaligreen, and Arimoto watched as it began to fly off the shelves. "It was a very moving experience," recalls Arimoto. "At first, I didn't think we would do so well, but we were inundated with so many orders that production couldn't keep up."

Kaligreen has since been approved for sale in 15 countries and the list keeps growing. Soon after it went on sale in the United States, a farmer growing grapes for organic wine requested that the fungicide be certified by the Organic Materials Review Institute. It was listed in 1999.

Kaligreen was the first of seven SaFE products that Arimoto's team has launched. The list includes the fungicides G-FINE and Harmomate, which also contain sodium bicarbonate. In November 2015, a remedy against a disastrous tomato virus was approved for release. "Bemidetouch Emulsion has an intriguing effect on the silverleaf whitefly," explains Arimoto. The silverleaf whitefly transmits the tomato yellow leaf curl virus, which stunts the growth of tomato plants, sometimes causing farmers to lose their entire harvests.

Arimoto's insect repellent contains a substance that tricks the whitefly into thinking that a plant is not the right species to parasitize. The male whitefly usually mates by sending out signals that lure female whiteflies to the same leaves. Bemidetouch prevents this pairing by weakening the male signal.

In 2011, Arimoto's decades of research were acknowledged when he received a national merit award for his contributions to industry, academia and government through the promotion of SaFE pesticides.

Fundraising for the RIKEN Centennial Project

2017 will mark the centennial of RIKEN's founding. To continue to serve as a fundamental research institute trusted by society, RIKEN plans to take this opportunity to deepen its ties with those who have supported the institute in the past and to develop new ties in Japan and overseas. RIKEN will be collecting contributions to commemorate the centennial anniversary and to carry out the RIKEN Centennial Project.

Use of donations

- Centennial Project laboratories
- Future leader fund
- Improvement of research facilities
- Centennial celebration
- Collecting, preserving, and displaying historical materials and records

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RIKEN Vitamin

In 1924, RIKEN researchers Katsumi Takahashi and Umetaro Suzuki succeeded in isolating and extracting vitamin A from cod liver oil, for the first time in the world. The vitamin supplement was later mass produced and sold as the popular product RIKEN Vitamin. The RIKEN cyclotron technology was used in the industrial-scale enrichment of vitamin A by distilling cod liver oil and crystallizing vitamin A at low temperature.

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