RIKEN

RESEARCH

IMMUNITY RESEARCH BEARS FRUIT

Boosting plant defences against pathogens

BACK STORY
Decoding the vertebral formula

AMYLOID BETA BUSTER
Natural mutation protects against Alzheimer's

MAGNETIC SWITCH
Converting heat into electricity

▲ **SPINAL SIGNATURES**
A comparative study of nearly 400 tetrapod species reveals that while mammals, such as humans and giraffes, share a consistent neck vertebra count, birds, reptiles and other groups show striking variation. Researchers at RIKEN have linked these differences to certain genes (*see page 13*).

ABOUT RIKEN

RIKEN is Japan's only comprehensive research institute for the natural sciences. It conducts advanced research across a wide range of fields, including physics, engineering, chemistry, mathematical and information sciences, computational science, biology, and medical science.

Founded in 1917 as a private foundation, RIKEN has undergone several transformations throughout its history. After operating as a company and later as a public cooperation, it was re-established in October 2003 as an Independent Administrative Agency under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). In April 2015, it became a National Research and Development Agency.

To ensure that the results of its research benefit society, RIKEN actively engages in joint and commissioned research with universities and private companies. It also promotes the transfer of intellectual property and technologies to industry.

RIKEN Research is an online and print publication that highlights the best research published by RIKEN in collaboration with Nature Custom Media, a part of Springer Nature.

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ISSN 1883-3519
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p.10

p.12

p.19

p.20

To our readers

Masashi Kawasaki
Executive Vice President and
Director of TRIP Headquarters

As detailed later in this issue (see page 28), one of my responsibilities as Executive Vice President is to oversee the RIKEN TRIP Program, which we established in 2022 with the goal to put in place a 'Transformative Research Innovation Platform' in order to effectively generate new fields of knowledge by cross-linking cutting-edge research activities that are being carried out at RIKEN.

Initially, we launched the Data and Computation Sciences Integration Research Program with the goal to further enhance RIKEN's strengths in areas such as data acquisition and mathematical and information sciences across research domains. We also aimed to develop new tools in areas such as generative 'AI for Science', hybrid high-performance computing (HPC), and quantum computing. RIKEN is truly a pioneer in this area, as few institutes are able to bring together teams of physicists in quantum and computational specialists in HPC. We recently announced our plans for our next supercomputer, tentatively named FugakuNEXT (see page 6), which will help us in this endeavor.

By promoting a major leap in computational power, we will contribute to the establishment of 'Society 5.0', meaning a sustainable society based on a fusion of cyberspace and physical space. Ultimately, it would be wonderful to see a world where we can access quantum algorithms through our phones!

Thanks to the efforts of our researchers during the years leading up to 2025, we have been able to plunge at full speed into our Fifth Mid-to-Long-Term Plan, which covers the coming seven years. I very much hope that this issue will help our readers to understand this challenge and will encourage them to collaborate with us for realizing this new research goal. We are fully aware that in today's complicated world, institutes, particularly those from smaller countries, must work across borders to tackle the problems faced by humanity, and look forward to working together.

COVER STORY:
A gene from pomelo trees helps plants spot pathogens by detecting cold-shock proteins—offering a powerful new tool to boost crop immunity and cut down on pesticides. *Page 30*

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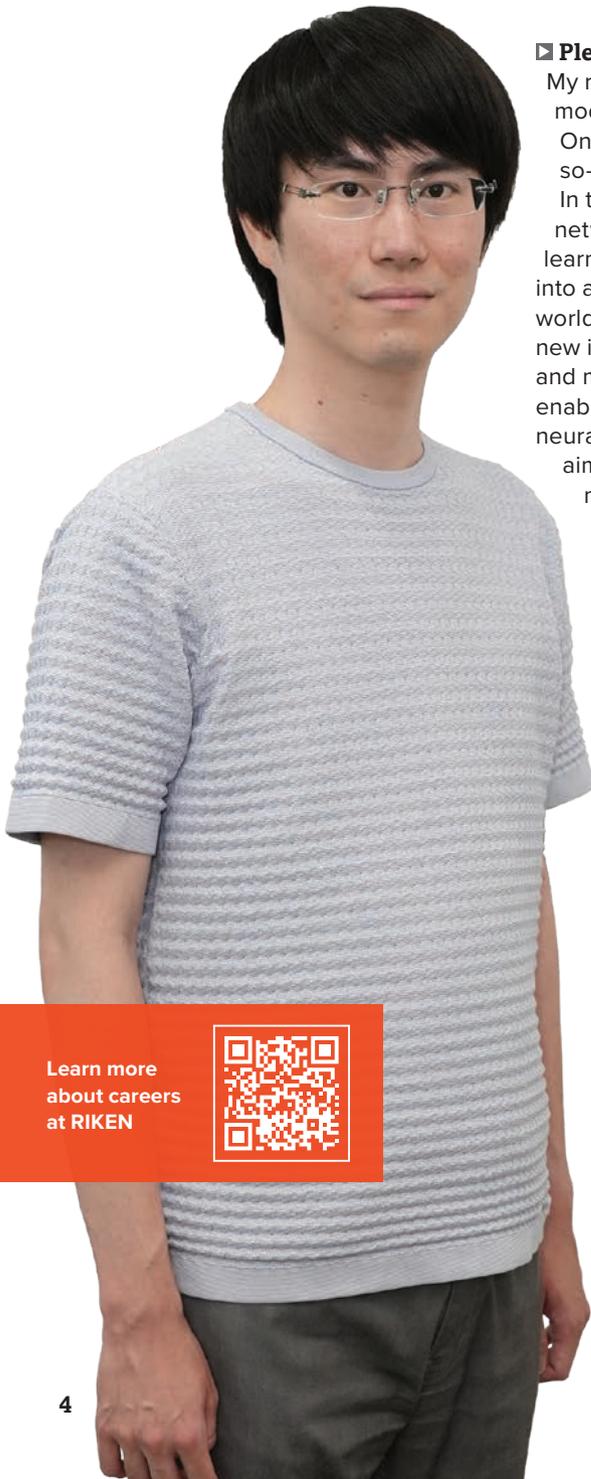**Facebook**
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Decoding how the brain learns

Toshitake Asabuki

RIKEN ECL Unit Leader, Hierarchical Neural Computation
RIKEN ECL Research Unit, RIKEN Center for Brain Science

▶ Please describe your research.

My research uses computational models to investigate brain function. One of the tools I use for this is a so-called recurrent neural network. In the brain, recurrent neural networks abstract and reorganize learned information and experiences into an 'internal model' of the external world. Learning occurs by comparing new inputs against this internal model and making predictions, thereby enabling efficient and sophisticated neural information processing. We aim to formalize this mechanism mathematically, and are developing theoretical models to test using experimental data. This will help us better understand the brain's flexible information processing.

▶ How did you become interested in your current research?

My interest in the brain stemmed from an illness that my mother had. Soon after I began my studies at Waseda University, my mother suffered a cerebral hemorrhage. She regained consciousness, but lost part of her memory. Over time, I witnessed her gradual cognitive recovery through rehabilitation. She began to recall events—not from recent memory—but in the order of her developmental timeline, from early childhood onwards. It was through that experience that I came to see the brain as a kind of system. That sparked my deep interest in neuroscience.

Learn more about careers at RIKEN

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

For me, one of the most interesting recent discoveries in theoretical neuroscience is the concept of neural manifolds. This framework suggests that, despite the high dimensionality of neural activity, population dynamics are often confined to neural manifolds, which are low-dimensional subspaces. These manifolds offer a powerful way to interpret trial-to-trial variability. It's an especially exciting concept because it brings together theory and experiment in a remarkably elegant way, providing deep insights.

> " *I saw my mother's brain rebuild itself—memory by memory.*

▶ My research is important for society because…

It bridges the gap between machine learning and biological brain function, which plays a crucial role in our understanding of how the brain learns and adapts. Using computational models to study synaptic plasticity (strengthening or weakening of connections in response to activity) allows us to interpret complex experimental data and develop models that make new predictions about neural computation. These insights contribute to the development of more effective treatments for neurological disorders and more flexible, adaptive artificial intelligence systems.

▶ What do you hope to achieve with your research in the future?

As I continue my neuroscience research at RIKEN, I'm also looking ahead to future contributions to AI. Current deep-learning systems require vast amounts of data and power. If we can build a mathematical model that mimics the brain's internal model-building and self-supplementing learning processes, we could develop more efficient AI systems—ones that achieve results with less data and energy consumption. ◼

Providing translation support to researchers

Maya Keeley

Deputy Manager, Translation Team
International Collaboration Section, Global Strategy Division

▶ **Tell us about your work at RIKEN.**
I work as a translator at RIKEN, which mainly involves translating documents from Japanese into English within the administrative departments. These include announcements, manuals and regulations and website content for various administrative divisions.

▶ **How and when did you join RIKEN?**
I applied to RIKEN after hearing it had an excellent translation team and a supportive working environment. I joined the translation team in 2012 and have been a member ever since.

▶ **What is your background?**
My mother is Japanese and my father is South African–Irish, and I've lived in South Africa, Australia and Japan. I studied psychology at university in Australia and then obtained a teaching qualification. After working as a school teacher for some time, I transitioned to translation.

▶ **What kind of support does RIKEN offer to its non-Japanese staff?**
When joining RIKEN, new members receive support through an English welcome session and also with practical matters such as visas, housing, Japanese-language classes, opening a bank account and mobile phone contracts. Most notices in the internal RIKEN network are also provided in English.

▶ **How was the transition to RIKEN?**
The transition was smooth. My team members are highly committed to supporting international researchers and RIKEN as a whole. They're cooperative and communicative, which made it easy for me to work here. Additionally, RIKEN offers excellent benefits and fosters a good work–life balance, allowing me to visit my family in Australia annually.

▶ **What is the hardest aspect of your job?**
The most difficult part is accurately conveying the nuances of a document when translating. Since documents often include cultural context, I carefully consider how to translate them in a way that best communicates the original meaning. Because most of our overseas researchers use English as a second language, we strive to translate in a easy-to-understand manner.

▶ **What would you say to someone considering joining RIKEN?**
RIKEN is Japan's largest comprehensive research institution, and we're known for our high-quality research across a diverse range of scientific disciplines. It's a place where you can contribute to cutting-edge research in an excellent work environment, with help from highly supportive staff. Living and working in Japan provides a unique opportunity to deeply experience a different culture and language, enriching both your personal and professional life.

▶ **What future plans do you have?**
I aim to contribute significantly to RIKEN's ongoing internationalization efforts. I hope to help improve the clarity and consistency of English-language documents, making them more accessible to everyone. Additionally, I want to continue to improve my own skills and knowledge to better serve the diverse RIKEN community and help create an inclusive, welcoming environment where everyone can thrive. ■

FugakuNEXT's architecture and NVIDIA collaboration launch

Marking a major milestone in Japan's next-generation computing, on August 22, 2025, RIKEN officially launch the development framework for the nation's new flagship supercomputing system, codenamed FugakuNEXT. This project will be the successor to the world-leading supercomputer Fugaku, which is based at RIKEN's Kobe Campus. RIKEN and Fujitsu Limited have been jointly developing the basic design of FugakuNEXT's overall system architecture, including compute nodes and CPU components.

August marked the solidification of the development framework and the decision to appoint NVIDIA Corporation from the United States as the official partner responsible for the GPU-based accelerator component — marking the first time that GPUs will be adopted in Japan's flagship supercomputing systems.

With this complete partnership in place, the three organizations will collaborate to build an advanced 'AI-HPC platform' aimed at solving pressing societal and scientific challenges through computational innovation. "It is a great honor

RIKEN President Makoto Gonokami (front middle right) and Ian Buck from NVIDIA Corp. (front right).

for RIKEN to collaborate with Fujitsu and NVIDIA in advancing the development of FugakuNEXT," says RIKEN President Makoto Gonokami, noting that the supercomputer will need to integrate knowledge spanning hardware, software and algorithms to achieve unprecedented performance. "In alignment with Japan's semiconductor strategy, and through strong collaboration with diverse domestic and international partners, the FugakuNEXT project will contribute to solving global challenges and fostering sustainable industrial growth," he adds.

www.riken.jp/en/news_pubs/
news/2025/20250822_1/

Supercomputer Fugaku and IBM Quantum System Two integration

On June 24, 2025, a ceremony was held at the RIKEN Center for Computational Science (R-CCS) in Kobe, Japan, to celebrate joint operations beginning between supercomputer Fugaku and IBM Quantum System Two.

The project is developing a hybrid computing platform that combines supercomputing with quantum computing to support advanced communication systems beyond 5G.

IBM Quantum System Two, now installed at R-CCS, features a 156-qubit Heron processor. It's the first installation of this system outside of North America. The integration of the two systems represents a new approach called 'Quantum-Centric Supercomputing', which blends the strengths of both technologies.

R-CCS, in partnership with SoftBank Corp., the University of Tokyo and Osaka University, is leading a government-funded project supported by the New Energy and Industrial Technology Development Organization (NEDO) under Japan's Ministry of Economy, Trade and Industry (METI).

This collaboration aims to push the boundaries of computing and develop technologies that can be used in real-world services, helping Japan lead in the next generation of information and communication systems.

Opening remarks were delivered by Makoto Gonogami, President of RIKEN; Akio Yamaguchi, President and CEO of IBM Japan, Ltd.; and Jay Gambetta, Vice President of IBM Quantum, which is based in New York in the United States. Congratulatory addresses from followed from Kisaburo Tokai, Chair of the Committee on Education, Culture, Sports, Science and Technology of the House of Representatives, Japan; Motohiko Saito, Governor of Hyogo Prefecture; Kizo Hisamoto, Mayor of Kobe City; Jingo Kikukawa, Director-General for Innovation and Environment at METI; and Tomoyasu Nishimura, Executive Director of NEDO, Japan. The ceremony was followed by a symposium that showcased past research and future goals.

www.riken.jp/en/news_pubs/
news/2025/20250701_2/

RIKEN President Gonokami and Her Excellency Stéphanie Obertin, Luxembourg's Minister for Digitalization, Research and Higher Education.

Luxembourg minister visits RIKEN to explore research collaboration

Her Excellency Stéphanie Obertin, Minister for Digitalization, Research and Higher Education of the Grand Duchy of Luxembourg, visited RIKEN's Wako Campus on July 14 and the Yokohama Campus on July 18, 2025, accompanied by His Excellency Michel Leesch, Ambassador of Luxembourg to Japan, and a delegation of government representatives.

At RIKEN's Wako Campus, RIKEN President Makoto Gonokami welcomed the delegation, followed by an overview of RIKEN from Executive Vice President Kyoko Nozaki. Shigeo Okabe, Director of the RIKEN Center for Brain Science (CBS), introduced CBS and led discussions on potential collaboration with Luxembourg research institutes. Romain Martin, Senior Government Advisor to Luxembourg's Ministry of Research and Higher Education, also presented the country's science and technology strategy. The visit included tours of the Laboratory for Brain Development and Disorders and the Neurodegenerative Disorders Collaboration Laboratory at RIKEN.

At the Yokohama Campus, Masayuki Amagai, Director of the RIKEN Center for Integrative Medical Sciences (IMS), and Deputy Director Haruhiko Koseki introduced IMS and its past collaborations with researchers in Luxembourg. Here, Martin again outlined Luxembourg's research strategy, followed by presentations from IMS Team Directors Eiryo Kawakami and Kosuke Miyauchi. The visit concluded with a tour of the NMR facility led by Senior Research Scientist Shunsuke Imai.
www.riken.jp/en/news_pubs/ news/2025/20250808_1/

Safeguarding the Earth's shared resources

On July 1, 2025, RIKEN signed a memorandum of understanding with the University of Tokyo, Japan, and the Potsdam Institute for Climate Impact Research, Germany. The aim is to build a scientific research infrastructure that supports the safeguarding of the global commons.

The global commons refers to Earth's systems and resources shared by all people—such as the atmosphere, oceans and ecosystems—that no single country owns. Safeguarding these systems is essential to keeping Earth safe and sustainable for current and future generations.

The agreement includes researcher exchanges; the sharing of scientific and technological information through lectures, seminars, and symposia; the sharing of research materials; joint research projects, publications and dissemination of research results; and other related activities.

As climate change, biodiversity loss and pollution worsen, research shows that continuing current human activities will make Earth unsafe for humans. Reports from the Intergovernmental Panel on Climate Change and studies on planetary boundaries highlight the urgent need to transform our societal systems to safeguard the Global Common—as a safe operating space for humanity shared by all.

The three institutions will collaborate in basic and systems science research, areas that have had limited cooperation in the past. This partnership aims to strengthen science that helps prevent the collapse of the Earth's systems.

RIKEN, Japan's largest research institution, will contribute high-quality data, bioresources and access to infrastructure, such as supercomputer Fugaku and synchrotron radiation facility SPring-8. The University of Tokyo will support the collaboration through its interdisciplinary expertise in political science, development studies, engineering and other fields. PIK will use its integrated assessment model to predict how RIKEN's research affects society and the Earth system.

Together, the three institutions aim to generate knowledge that supports a transformation of the socioeconomic system to safeguard the global commons and help build a sustainable future for all.
www.riken.jp/en/news_pubs/ news/2025/20250722_1/

Officials from RIKEN, the University of Tokyo and the Potsdam Institute for Climate Impact Research.

EXOSKELETONS

Combining AI and exoskeletons reduces the strain on users

AI-informed exoskeletons operate more efficiently, requiring less effort from wearers

Two RIKEN researchers have developed an exoskeleton that incorporates AI, making it easier to use in real-life environments[1]. The exoskeleton operates based on the user's status and view of the environment.

An exoskeleton is a wearable robot that assists wearers to perform actions that would be difficult or impossible for them to do unaided. Exoskeletons are attracting special attention in aging societies such as Japan, as they could assist the elderly and those who look after them.

Exoskeletons typically work by implementing preprogrammed motions that the wearer has to select. This makes it difficult for them to perform a wide range of motions in real-life environments.

AI-powered exoskeletons adapt to users and environments for smarter support.

To realize more flexible exoskeletons that move in accordance with the wearer's intention, control approaches that estimate the wearer's intended motion are being studied. They are expected to be applied to a wide range of
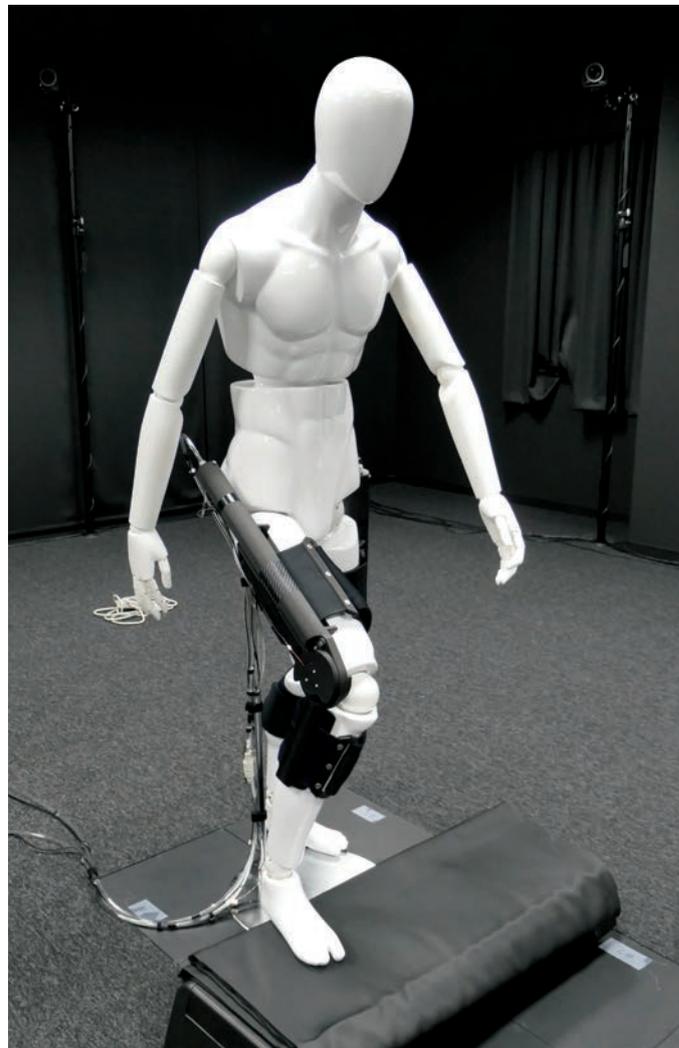
motions in real-life scenarios.

Attempts to include the wearer in the loop usually involve placing sensors on muscles and using them to detect when the wearer is attempting to make a movement. But installing and calibrating sensors requires time and effort, making this approach difficult to apply in the field.

To address these limitations, Jun-ichiro Furukawa and Jun Morimoto, both of the RIKEN Guardian Robot Project, investigated whether combining AI with a visual sensor could enhance an exoskeleton's efficiency.

The pair developed a system where an AI, in this case a transformer model, receives inputs from a camera placed near the user's eyes and kinematic sensors around the knees and torso, and then uses this rich set of inputs to provide assistance for a series of tasks. In this case, the tasks were picking up an object and then climbing a step—representative of common daily activities that require different types of physical support.

The results were compelling. The AI-powered assistance system led to a measurable reduction in muscle activation during these movements, indicating that the exoskeleton was effectively supporting the user's body.

"This study represents an important step toward intelligent

AI can assist an exoskeleton perform tasks such as walking up steps, RIKEN researchers have shown.

exoskeletons that can support a wide range of human activities in diverse environments," comments Morimoto.

Importantly, the assistive strategy developed from one user's data could be generalized to another user, suggesting that the model is capable of cross-user adaptability without retraining—a significant challenge in current exoskeleton technologies.

"By using transformer-based AI, our system not only adapts to the current user's physical state and surroundings but also shows potential for generalized

assistance across different users," notes Morimoto.

"These findings open new doors for future applications of wearable robots in areas such as healthcare, rehabilitation and elderly care," says Furukawa. ●

Reference
1. Furukawa, J. & Morimoto, J. Transformer-based multitask assist control from first-person view image and user's kinematic information for exoskeleton robots. *npj Robotics* **3,** 13 (2025).

ALCOHOL METABOLISM

Japanese drinkers display three different responses to alcohol

Three different responses to alcohol experienced by Japanese people depends on their genetics

The subjective responses of Japanese people to alcohol can be classified into three clear clusters, RIKEN researchers have discovered[1]. This finding could help identify people who are at risk of alcohol-related disorders.

Japanese people and other East Asian populations have genetic variations that affect their response to alcohol. These are variants of two major genes that affect the metabolism of alcohol: *ADH1B*, which is involved in converting alcohol into the toxic chemical acetaldehyde, and *ALDH2*, which is involved in transforming acetaldehyde into the non-toxic compound acetate.

Many Japanese people harbor a gene variation that accelerates the conversion of alcohol into acetaldehyde. But in addition, many also have a variation in the *ALDH2* gene that makes it harder for them to convert acetaldehyde into acetate—this is responsible for the so-called Asian flush.

But how these genetic variations affect people's subjective experience of these reactions to alcohol was previously not well understood.

Now, a group led by Chikashi Terao of the RIKEN Center for Integrative Medical Sciences (IMS) has discovered that 429 healthy young people could be clustered into three groups—those who quickly felt the effects of the alcohol; those who gradually felt the effects grow over time; and others who were relatively intolerant to the effects.

Further, these clusters were associated with certain

Japanese people exhibit one of three subjective reactions on drinking alcohol, RIKEN researchers have found.

combinations of variations in several genes, including the two major ones. This implies that genetic testing could help predict the subjective responses of people to alcohol.

"Although it was previously thought that various combinations of risk alleles in *ALDH2* and *ADH1B* produced a wide range of alcohol sensitivities, we discovered, unexpectedly, that they can be simplified into just three patterns," says Keiko Hikino, also of IMS.

The team sequenced the genomes of the subjects, and then had them receive alcohol intravenously over several hours to maintain a given blood-alcohol level.

The subjects were also asked to fill out reports every 30 minutes describing whether they had feelings such as being high, sleepy or uncoordinated, which are symptoms typical of drunkenness.

The finding of this study could have practical outcomes for clinicians. "Alcohol is a common part of daily life, but it's responsible for many deaths, and its effects on health are of interest to many people," says Terao. "Our finding that alcohol response in the Japanese population can be classified into three distinct types should make it easier to identify and intervene with individuals at

higher risk of alcohol-related health problems."

"The current study focused on healthy young adults, but in the future, we aim to extend our research toward identifying risk factors for alcohol dependence," says Hikino. ●

Reference
1. Hikino, K., Otsuka, I., Oshima, S., Hishimoto, A., Ozaki, K., Liu, X., Ishikawa, Y., Mushiroda, T., Matsushita, S. & Terao, C. Unraveling time-dependent genetic components underlying alcohol response. *Neuropsychopharmacology* **50,** 1665–1673 (2025).

MEMBRANE LIPIDS

Lipid 'nanodomains' hold the key to cell signaling mystery

The role that tiny globules of fat in the cell membrane play in regulating an important protein has been imaged on a molecular level

Tiny blobs of fats, or lipids, in cell membranes regulate the activity of a cancer-linked protein, cell biologists at RIKEN have discovered[1]. This finding could pave the way for new approaches to treating cancer.

Lying within the thin, flexible membranes that encase cells are tiny clusters of specialized lipids that help to steer critical growth signals. But just how these structures, known as nanodomains, coordinate these processes has long been a mystery.

The key role nanodomains play in regulating the activity of the epidermal growth factor receptor (EGFR)—a protein implicated in cell growth and division, and also cancer—has now been uncovered by a team led by bioimaging specialist Yasushi Sako of the RIKEN Cellular Informatics Laboratory.

Lipids in the membrane actively shape protein function to fine-tune cellular responses.

The RIKEN team captured the intricate choreography between lipid nanodomains and EGFR in living cells using super-resolution microscopy, which was capable of imaging single molecules.
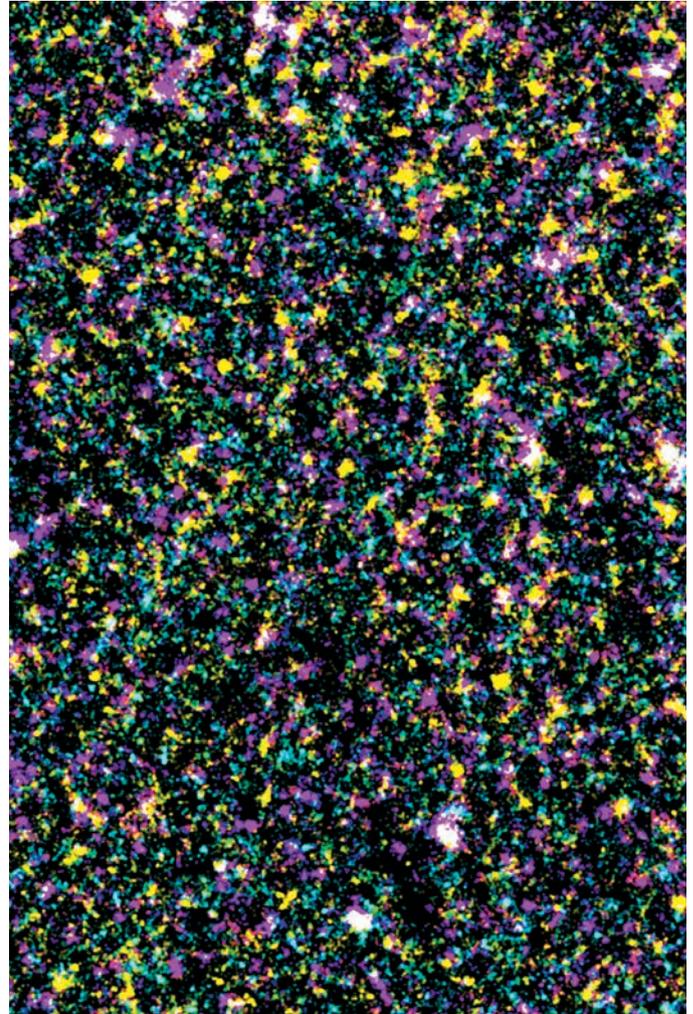
The nanodomains—some of which contain a charged fat molecule called 'PI(4,5)P2'—activate EGFR by orchestrating key molecular interactions. After completing this task, the nanodomains dismantle themselves, thereby deactivating EGFR. This ensures precise and dynamic control of cellular signaling.

"The PI(4,5)P2 nanodomain supports EGFR activation, while activated EGFR dissolves the nanodomain structure," explains lipid biologist Mitsuhiro Abe, also of the RIKEN Cellular Informatics Laboratory.

This dynamic remodeling of the lipid environment reveals a previously underappreciated mechanism of signal regulation, where lipids in the membrane actively shape protein function to fine-tune cellular responses.

This finding challenges the view of the cell membrane as a passive boundary. Instead, the membrane emerges as an active regulator, shaping how signaling proteins function to maintain cellular balance and control.

Nanodomains are far too tiny to be observed with conventional fluorescence microscopy. And so the team employed advanced single-molecule localization microscopy to track interactions between EGFR and PI(4,5)P2 lipids with unprecedented precision.

A microscopy image shows the distribution of epidermal growth factor receptor (cyan) and PI(4,5)P2 (magenta) in a cell membrane.

"This research was accomplished by combining the fields of lipid biology and cell biophysics," notes Abe. This interdisciplinary approach allowed the team to precisely observe how nanodomains cluster around EGFR before stimulation, enhancing its activation.

The team's discovery opens the door to developing new therapeutic strategies for cancer and hereditary syndromes, for which EGFR and related signaling proteins are often implicated. The lipid-mediated regulation uncovered by the team suggests that targeting not just EGFR, but also the lipid environment controlling it, could offer a novel approach to addressing tumors driven by aberrant signaling, potentially improving treatment outcomes. ●

Reference

1. Abe, M., Yanagawa, M., Hiroshima, M., Kobayashi, T. & Sako, Y. Bilateral regulation of EGFR activity and local PI(4,5)P2 dynamics in mammalian cells observed with superresolution microscopy. *eLife* **13**, e101652 (2024).

QUANTUM INFORMATION

Extending the applicability of a quantum law

Even quantum systems with long-range interactions can be analyzed using a known principle

By extending a key law in quantum information to systems with long-range interactions, RIKEN physicists have enhanced its usefulness[1]. This advance could help to design better quantum computers.
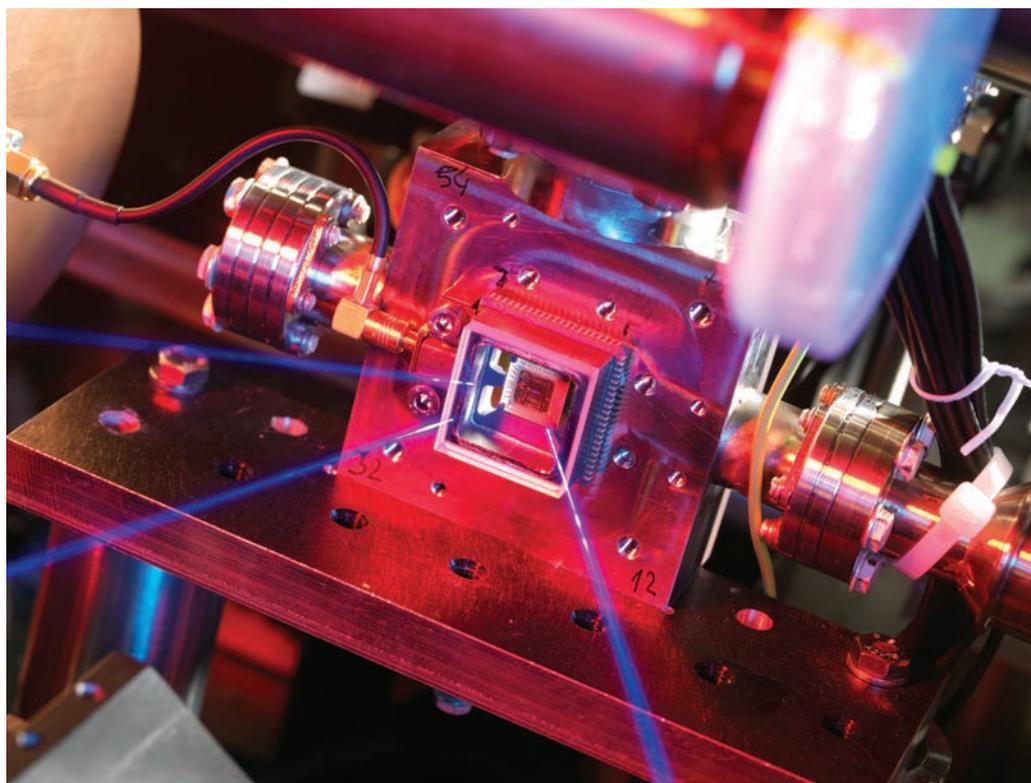
Compared with their classical counterparts, systems made up of many quantum particles—such as quantum computers—are horrendously complex to analyze and simulate. This complexity is due in part to the strong correlations between particles, which can act over long distances.

One helpful principle for understanding systems in which the quantum particles are split into two groups is the area law. It states that the amount of information shared between the two parts of a quantum system depends on the boundary between them rather than the total size of the two parts.

"This idea provides profound insights into how information is structured in nature and has far-reaching implications across physics, helping researchers explore phenomena ranging from exotic phases of matter to black holes," says Donghoon Kim of the RIKEN Center for Quantum Computing (RQC).

The area law simplifies the analysis of large quantum systems because it means it is not necessary to know all the details about the entire system, but just how the two parts are connected across their boundaries.

However, the area law has only been shown to apply to systems that have short-range interactions between their

Ion traps, such as the one shown here, are one promising technology for developing quantum computers. Trapped ions are also an example of a long-range interacting system that the area law can be applied to.

particles. That excludes many systems of great interest.

"In many important physical systems, particles interact with others far away—not just their neighbors," explains Kim. "These long-range interacting systems are essential for understanding both the large-scale structure of the Universe and the behavior of complex quantum materials."

Now, Kim, Tomotaka Kuwahara, also of RQC, and Keiji Saito of Kyoto University have shown that the area law at finite temperatures also applies to long-range interacting systems under certain conditions.

"Our result suggests that, by

carefully choosing meaningful and realistic assumptions, we can extend the reach of mathematical analysis into areas that were once thought to be out of bounds," says Kim.

The trio's achievement has important implications for practical applications of quantum systems such as quantum computers.

"We now have a much clearer understanding of when and how quantum systems can be simulated efficiently at finite temperatures," says Kim. "This is especially relevant for quantum computing and quantum simulation, where

managing entanglement and thermal correlations is a major challenge."

The result can help guide the design of algorithms and hardware by identifying the regimes where quantum information remains localized and tractable—even when long-range interactions are present, Kim notes. ●

Reference
1. Kim, D., Kuwahara, T. & Saito, K. Thermal area law in long-range interacting systems. *Physical Review Letters* **134,** 020402 (2025).

AI-assisted simulations reveal the dynamic evolution of a galaxy shaped by supernova explosions—accelerating discovery of these events from years to months. This is a simulated galaxy after 200 million year done with (right) and without (left) a new machine learning AI model.

GALAXY EVOLUTION

Simulating galaxy evolution on a much faster timescale

By using machine learning, astrophysicists have cut the computing time needed to simulate supernovae that drive the evolution of galaxies

RIKEN researchers have dramatically reduced the processing time needed to simulate galaxy evolution powered by supernova explosion[1]. Their approach, which uses machine learning, a type of AI, could help scientists determine the origins of our own galaxy.

Understanding how galaxies form is a central problem for astrophysicists. Cataclysmic events, such as supernovae can drive galaxy evolution, but it is not possible to observe them in real time.

Instead, scientists rely on numerical simulations based on large amounts of data collected from telescopes and other instruments that measure aspects of interstellar space. Simulations account for gravity, hydrodynamics and astrophysical thermochemistry.

Furthermore, they must have a high temporal resolution, meaning that the time between each 3D snapshot of an evolving galaxy must be short enough not to miss any critical events. For example, capturing the initial expansion of a supernova shell requires a timescale of mere hundreds of years—1,000 times smaller than typical simulations of interstellar space can achieve.

A typical supercomputer takes 1–2 years to perform a simulation of a relatively small galaxy at the proper temporal resolution.

A team led by Keiya Hirashima of the RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences has overcome this timestep bottleneck.

By incorporating AI into their data-driven model, they were able to match the output of a previously modeled dwarf galaxy.

"Our AI-assisted simulation was able to reproduce the dynamics important for capturing galaxy evolution and matter cycles, including star formation and galaxy outflows," says Hirashima.

But they obtained the result much faster. "When we use our AI model, the simulation is about four times faster than a standard numerical simulation," says Hirashima. "This corresponds to a reduction of several months to half a year's worth of computation time."

Like most machine learning models, the new model is trained using one set of data and then becomes able to predict outcomes based on a new set of data. In this case, the model incorporated a programmed neural network and was trained on 300 simulations of an isolated supernova in a molecular cloud with a total mass equivalent to one million of our suns.

"Our AI-assisted framework will allow high-resolution, star-by-star simulations of heavy galaxies, such as the Milky Way, with the goal of predicting the origin of the solar system and the elements essential for the birth of life," says Hirashima.

The team is now using the new framework to run a simulation of a galaxy the size of the Milky Way. ●

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ANATOMY

Investigating the link between genes and vertebrae in tetrapods

A clear link between the arrangement of vertebrae in the spine and certain genes holds for mammals, but not for birds and amphibians

By analyzing the arrangement of vertebrae in the spines of nearly 400 tetrapod species, RIKEN researchers have found some follow a predicted pattern, whereas others do not[1].

Your neck has the same number of bones as a giraffe's. In fact, nearly all mammals have seven neck vertebrae. In contrast, birds have anywhere between 9 and 25.

Of the five spine regions, the neck is nearest to the head. The other four are the regions around the rib cage, lower back, pelvis and tail.

The number of vertebrae in each region varies between species; it is known as the vertebral formula. For humans, it is typically '7, 12, 5, 5, 4'.

A team at the RIKEN Center for Biosystems Dynamics Research (BDR) has been exploring the patterns in the vertebral formula between different species, and the underlying explanations for them.

"There's a tight connection between the vertebrae and *Hox* genes," explains biophysicist Rory Cerbus, a member of Kyogo Kawaguchi's team. "We speculated that the genes, or something regulating them, is behind the different vertebral formulae of different species."

Hox genes are interesting "because they're highly conserved, occurring in many species, from flies to humans," says Kawaguchi. "They're involved in determining the body's makeup."

Now, Cerbus, Kawaguchi and Ichiro Hiratani, all of BDR, have amassed the most comprehensive dataset of complete vertebral counts for tetrapods, including some long-extinct species. This research involved visiting natural history museums, examining computed-tomography scans, and scouring anatomical books.

Using this database, the trio investigated the relationship between the vertebral formula and *Hox* genes across various species.

"Perturbing *Hox* genes in mice often yields a particular change in the vertebral formula: if one section gains a vertebra, a neighboring section loses one," explains Cerbus. "Thus, if *Hox* genes are responsible for determining the vertebral formula in all tetrapods, you would expect to find signs of these neighborly exchanges when comparing different species."

The team did observe these patterns for mammals. But they also found that other groups of tetrapods broke that pattern.

"We anticipated there might be this neat picture, where all the species-to-species variation in the vertebral formula would be in the form of vertebrae shifting between neighboring sections," says Cerbus. "Since we saw that in mammals, it means that line of thinking is in the right direction. If you want to study the diversity in the body plan of mammals, *Hox* genes are apparently really important."

However, since not all tetrapods follow this pattern, the picture is more complex when you look across the wider group of animals. *Hox* genes are still doing something in groups such as birds and amphibians, says Kawaguchi, "but apparently they're used in a different way." ●

A skeleton of a Steller's sea eagle, of northeastern Asia, one of more than 388 tetrapods that a RIKEN team analyzed. The researchers determined its vertebral formula to be '13, 6, 0, 15, 8'.

Reference
1. Cerbus, R. T., Hiratani, I. & Kawaguchi, K. Homeotic and nonhomeotic patterns in the tetrapod vertebral formula. *Proceedings of the National Academy of Sciences of the USA* **121,** e2411421121 (2024).

Our circadian clocks remain remarkably constant in both cold and hot conditions. RIKEN researchers have discovered that the shapes of rhythms in messenger-RNA levels are important to this ability.

CIRCADIAN RHYTHMS

How our body keeps time in the heat

The mechanism by which body clocks remain constant even when the temperature goes up and down has been uncovered

RIKEN researchers have discovered how our biological clocks maintain a consistent 24-hour cycle despite fluctuating temperatures[1]. The insights could help better understand jet lag and sleep disorders.

Our bodies know when it's time to sleep or wake up because they have biological clocks that run on a roughly 24-hour cycle. We become conscious of this when our bodies become out of sync after traveling across time zones.

But it wasn't known how our bodies compensate for changing temperatures throughout the year since most chemical reactions speed up as temperatures rise.

Our biological clocks are powered by cyclical patterns in messenger RNA (mRNA)—the molecules that code for the production of proteins. These cycles result from certain genes being rhythmically turned on and off. They can be described mathematically by a sine wave, like the swing of a pendulum.

Now, a team of theoretical biologists and theoretical physicists led by Gen Kurosawa of the RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences has drawn on theoretical physics to analyze the mathematical models that describe this rhythmic rise and fall of mRNA levels. Specifically, they used the renormalization group method, a powerful approach adapted from physics, to extract critical slow-changing dynamics from the system of mRNA rhythms.

Their analysis revealed that at higher temperatures mRNA levels should rise faster and decline more slowly, but importantly, the duration of one cycle should stay constant. When plotted, this high-temperature rhythm looks like a skewed, asymmetrical waveform.

To test this theory in real organisms, the researchers examined experimental data from fruit flies and mice. Sure enough, at higher temperatures, these animals showed the predicted waveform distortions, confirming that the theoretical predictions align with biological reality.

The researchers concluded that waveform distortion is the key to temperature compensation in the biological clock, specifically the slowing down of mRNA-level decline during each cycle.

"Our findings show that waveform distortion is a crucial part of how biological clocks remain accurate and synchronized, even when temperatures change," says Kurosawa.

He adds that future research can focus on identifying the exact molecular mechanisms that slow down the decline in mRNA levels, which leads to the waveform distortion. Scientists hope to explore how this distortion varies across species—or even between individuals—since age and personal differences may influence how our internal clocks behave.

"In the long term, the degree of waveform distortion in clock genes could be a biomarker that helps us better understand sleep disorders, jet lag, and the effects of aging on our internal clocks," says Kurosawa. ●

Reference
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TERAHERTZ SPECTROSCOPY

Simpler is better when it comes to terahertz time-domain spectroscopy

Simplifying the experimental setup of spectroscopy based on terahertz waves makes it much faster and more stable

A simple tweak to the usual setup is all that is needed to enhance a spectroscopy technique that uses waves in the terahertz region to probe samples, RIKEN physicists have discovered[1,2].

Developing techniques that can obtain spectra from tiny regions extremely rapidly is the ultimate goal of a team that Norihiko Hayazawa of the RIKEN Center for Advanced Photonics belongs to.

Until recently, the scientists had been focusing on obtaining spectra from nanoscale regions on samples. But now they are concentrating on acquiring spectra very quickly—on the order of billionths of seconds (nanoseconds)—to minimize fluctuations induced by the ambient environment.

> ## "I had this vague hunch that the higher harmonics might behave differently."

To achieve that, Hayazawa turned to terahertz time-domain spectroscopy, which uses short pulses of electromagnetic waves that lie between microwaves and infrared radiation on the electromagnetic spectrum.

Because the signal in terahertz time-domain spectroscopy is weak, most experimental setups add external modulation to the signal for lock-in detection. This allows the signal to be easily distinguished from noise.
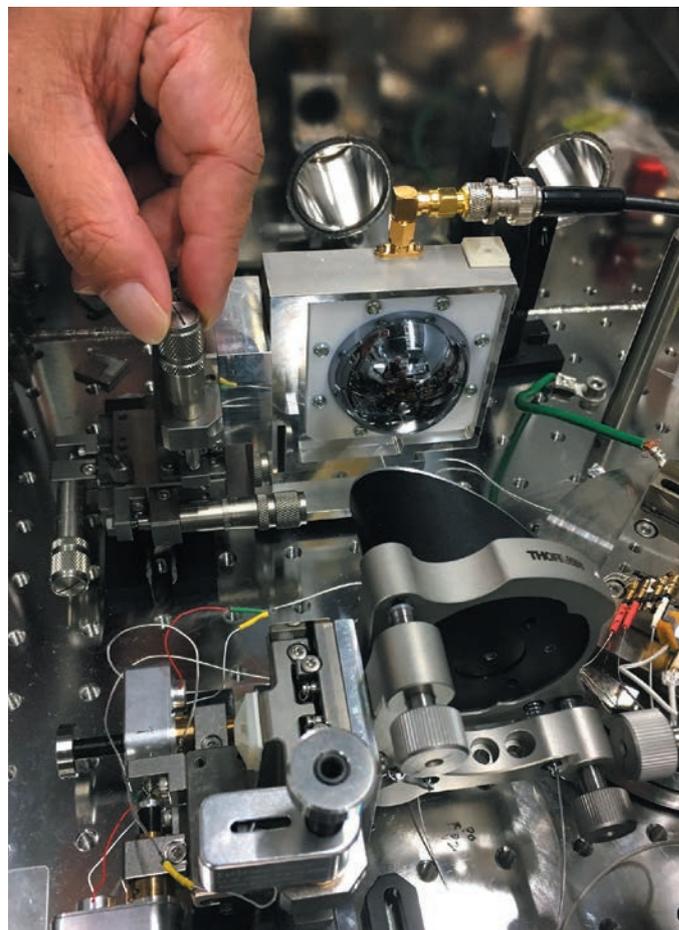
Being new to the technique, Hayazawa wondered whether this external modulation was necessary since the train of very short laser pulses used to create the terahertz pulses could provide much faster, intrinsic modulation.

"I'm not really a terahertz spectroscopy person," he says. "As a beginner, I naively wondered why don't we remove the external modulator? That would simplify the system a lot, plus it would make it much faster to acquire spectra."

The idea worked—provided there was no movement in the lab. But the measurement was extremely sensitive to disturbances, so that even the slightest movement of the operator would disrupt the signal.

"It was useless from a practical perspective," says Hayazawa. "If you stayed very still far away from the system, it worked fine. But the signal would fluctuate wildly as soon as you stood up or moved around."

At that point, it occurred to Hayazawa that he could check to see what was happening to the higher harmonics demodulations of the lock-in signal. Because

A close up of the simplified experimental setup for terahertz time-domain spectroscopy demonstrated by Norihiko Hayazawa and his team.

the terahertz pulses were not perfectly smooth sinusoidal pulses, they created signals at higher frequencies.

When Hayazawa checked the higher harmonics, he found they were virtually insensitive to movement.

"I had this vague hunch that the higher harmonics might behave differently," recalls Hayazawa. "But I was still really surprised when we checked the data and saw they were so stable."

The new scheme offers multiple advantages over the conventional one. "It's very fast and stable," he says. "And because we don't need an external modulator anymore, the system is much simpler."

Hayazawa is keen to spread the news about its benefits to the research community. A lock-in manufacturer has expressed interest in developing instruments based on it. ●

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2. Balgos, M. H., Hayazawa, N., Tani, M. & Tanaka, T. Electromagnetic wave detection: instrumentation and method. Japanese Patent Application No. 2024-103679.

ANTIFERROMAGNETS

Antiferromagnet shows promise for harvesting energy

A new magnetic material is very effective at changing heat into electricity

RIKEN physicists have found a magnetic material that converts heat into electricity with high efficiency, making it promising for use in energy-harvesting devices[1].

Photos you take on your smartphone are saved as a series of zeros and ones in a ferromagnetic material—magnetic materials that resemble iron in that their magnetic moments all point in the same direction.

Ferromagnets are easy to manipulate, making it easy to save data. However, because their magnetic moments are all aligned, they generate strong magnetic fields, and so it is not possible to cram a lot of them into a small space.

> **"We were surprised at how large the conversion efficiency for this material was…"**

Antiferromagnetic materials are the opposite to ferromagnetic ones in that their magnetic moments point alternately in opposite directions. Because their magnetic moments cancel out, it is possible to pack them much more tightly than ferromagnets. But the same property makes it tricky to read and write from them.

A special type of antiferromagnetic material known as a non-coplanar antiferromagnet, in which the magnetic moments don't lie in the same plane, exhibits the best aspects of both materials. Like other antiferromagnetic materials, they have zero net magnetic field overall. But their magnetic building blocks are tetrahedrons, making them much easier to manipulate.
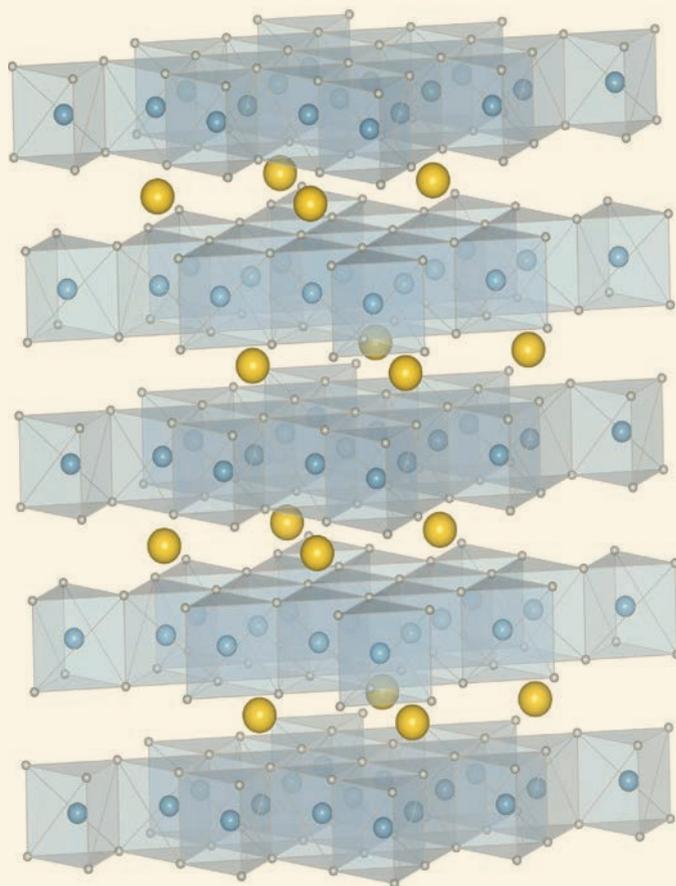
In addition to data storage, antiferromagnets are also promising for producing electricity from heat, and they could thus be used in energy-conversion devices.

Now, Duy Khanh Nguyen, who was based at the RIKEN Center for Emergent Matter Science at the time of the study, and co-workers have found a compensated antiferromagnet with non-coplanar spin texture that exhibits a very large heat-to-electricity conversion efficiency.

"We were surprised at how large the conversion efficiency for this material was despite its overall magnetization being tiny," says Nguyen, who is now at the University of Tokyo.

When the team modeled their material, they obtained excellent agreement with their experimental measurements.

The secret to the large conversion efficiency lies in the material's unique crystal, magnetic, and electronic structures and their symmetries. The interplay between them gives rise to hot spots of a 'fictitious' magnetic field within the material, which in turn causes the large conversion efficiency.

Nguyen and his team now intend to look for other compensated antiferromagnets that have even better properties. There are lots of possibilities for materials with the same structure, since the three elements making up the material can readily be substituted for other elements (see image).

"The chemical composition of this material is very flexible," notes Nguyen. "By adjusting its composition, we should be able to enhance the conversion efficiency."

The ability to simulate electronic properties using numerical calculations on large computer clusters will greatly aid the team's search, they say. ●

The chemical structure of the compensated antiferromagnet. Gold spheres represent cobalt atoms, blue spheres are niobium atoms, and gray spheres are sulfur atoms.

Reference
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PUBERTY

How hunger pangs push back the onset of puberty

A neural connection between sensations of hunger and the delayed onset of puberty has been teased out for the first time

The neural circuit responsible for delaying the onset of puberty in underfed mice has been discovered by neuroscientists at RIKEN[1]. The same circuit is expected to play a similar role in humans too.

Having offspring places large demands on female mammals, and they need adequate food to be able to bear them. There is a natural mechanism that limits pregnancies during times of food shortages—the onset of puberty is delayed in young, undernourished females.

Interestingly, the opposite effect may be at work in women in the developed world today. "Women today tend to experience puberty earlier than previous generations," notes Kazunari Miyamichi of the RIKEN Center for Biosystems Dynamics Research (BDR). "This is likely influenced by increased consumption of high-fat, processed foods."

Conversely, malnourishment or anorexia can push back puberty in girls. But the mechanism that determines the timing of the onset of puberty based on food availability has not previously been well understood.

Now, Miyamichi and Teppei Goto, also of BDR, and their co-workers have uncovered the neural pathways in female mice that connect feelings of hunger with the delayed onset of puberty.

They found that, in well-fed mice nearing puberty, neurons in the hypothalamus that produce kisspeptin—a protein that plays a crucial role in regulating reproductive hormones—exhibit

Giving birth to young places a large burden on mammalian mothers, and so the onset of puberty is delayed when food is in short supply. A team at RIKEN has discovered the neural connection behind this mechanism.

pulsatile activity in which hundreds of them fire synchronously and repeatedly. This pulsatile activity became more frequent, the closer a mouse came to puberty.

But in underfed mice, neurons in the arcuate nucleus—a center in the hypothalamus that registers hunger—reduced the frequency of the pulsatile activity, effectively applying the brakes to the onset of puberty.

At first, Miyamichi thought that hormones might act as the go-between between malnutrition and kisspeptin neuron activity. But the response was much too rapid for that.

"A major surprise was the

discovery that, once food becomes available, the pulsatile activity of kisspeptin neurons recovers remarkably quickly—within just a few hours," says Miyamichi.

That finding prompted his team to look into fast-acting neural pathways involved in the sensing of hunger and satiety.

It is highly likely that a similar mechanism operates in people too, Miyamichi believes. "Given the highly conserved nature of the protein-expressing neurons and kisspeptin in the human arcuate nucleus, there's little reason to doubt that similar mechanisms operate in humans," he says.

For Miyamichi, this study is just the beginning. "I believe there's much more to uncover during the juvenile-to-adolescent period—a developmental window that remains relatively underexplored in neuroscience, which has traditionally focused on the adult brain," he says. ●

Reference
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Using the supercomputer Fugaku (shown here), RIKEN researchers were able to determine the strong force acting between a nucleon and a charmonium.

QUANTUM CHROMODYNAMICS

Calculating the strong attraction of a charming particle

Calculations pin down the strong attraction between a proton or neutron and a charmonium

A theoretical study by RIKEN physicists has accurately determined the interaction between a charmonium, a state of a charm quark, and a proton or neutron for the first time[1].

From two galaxies colliding to an electron jettisoned from a nucleus, all interactions in the Universe can be described in terms of just four fundamental forces. Gravity and the electromagnetic force are the two we are often familiar with in everyday life, while the weak and strong forces operate over miniscule distances—roughly the size of an atomic nucleus or smaller.

As its name implies, the strong force is the strongest of the four forces over minuscule distances, and it binds protons and neutrons (collectively known as nucleons) within the atomic nucleus. It operates between quarks and gluons, which are the building blocks of nucleons.

"Nuclear power plants generate electricity by harnessing the strong force, and the Sun's energy is basically derived from it," says Yan Lyu of the RIKEN Interdisciplinary Theoretical and Mathematical Sciences Program. "So it's important to understand how the strong interaction works."

The strong force is described mathematically by quantum chromodynamics. While the theory is complete, how it operates in specific situations is an area of active research, both theoretically and experimentally in facilities such as particle accelerators.

Now, Lyu and co-workers have used quantum chromodynamics to theoretically investigate strong interactions between a nucleon and a type of short-lived particle called a charmonium.

Nucleons are made from up and down quarks, which are two of the six types of quarks. A charmonium, on the other hand, consists of a charm quark and a charm antiquark.

"The discovery of the first charmonium in November 1974 is sometimes referred to as the November Revolution because it was such a groundbreaking event in particle physics," says Lyu. "The two scientists involved were awarded Nobel prizes just two years later."

While the charmonium was discovered more than half a century ago, many questions remain about how it interacts with other particles.

"One fundamental question is how charmonia interact with nucleons," says Lyu. "That's the basic question we addressed in this study."

Performing calculations on Fugaku (see image), one of the world's most powerful supercomputers, Lyu and collaborators found that the interaction between the two particles was attractive at all distances. They were also able to pin down its magnitude much more accurately than previous estimates.

Experimental confirmation of the results may not be far off. "Experimentalists at the Large Hadron Collider in Europe said they're planning to measure the interaction between a nucleon and a charmonium in a few years," says Lyu.

The team plans to broaden their investigation. "We expect our findings will also be applicable to other systems," says Lyu. "That's something we're investigating now." ●

Reference
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SCANNING TUNNELING MICROSCOPY

Making excitons on demand in single molecules

Excitons have been created by injecting an electron into a molecule, and then removing another one, in rapid succession

In an exquisitely precise experiment, RIKEN scientists have shown that they can create quasiparticles known as excitons on demand in a single molecule[1]. This approach for studying ultrafast processes on a single-molecule level will help advance new quantum devices and catalysis.
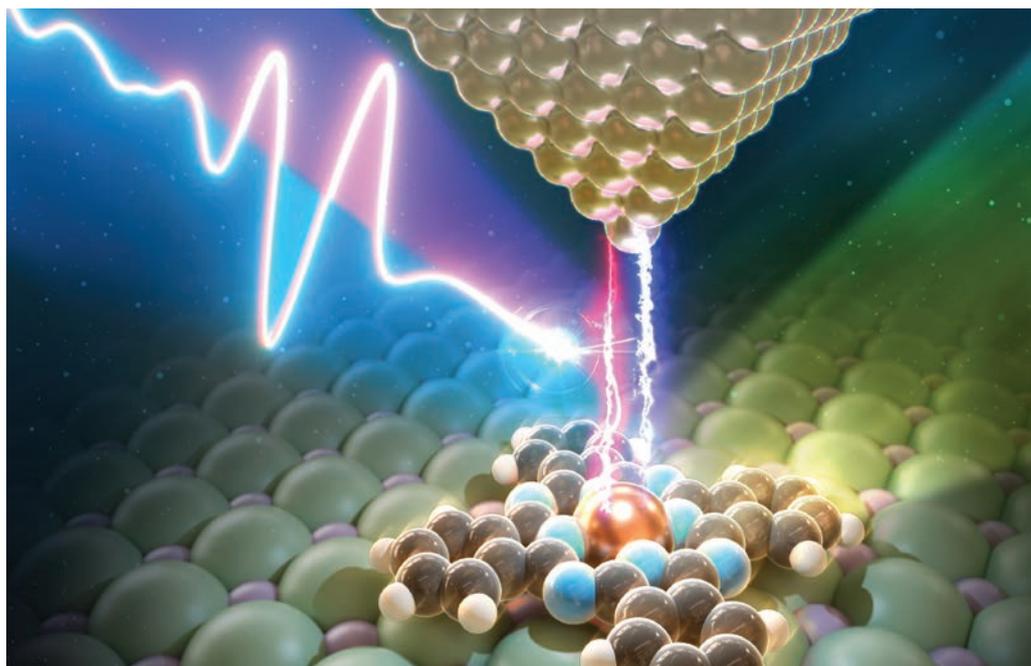
The transfer of charge between a metal electrode and a molecule underpins many key devices, including organic LEDs, organic solar cells and molecular sensors. It is also a critical process in catalysis.

Charge transfer could be used to create excitons in a molecule. An exciton is a negative electron paired with its positive counterpart—a hole (the absence of an electron). Excitons are essential to the operation of many optoelectric and molecular quantum devices.

"These devices exploit excitonic dynamics to achieve high-efficiency light emission or charge separation," notes Yousoo Kim of the RIKEN Surface and Interface Science Laboratory (SISL). "Understanding how excitons are created, evolve and decay at the single-molecule level is essential for both fundamental molecular science and the development of next-generation optoelectronic technologies."

One way to use charge transfer to create an exciton in a molecule would be to use the tiny metal tip of a scanning tunneling microscope to first inject an electron into the molecule and then remove another electron from it (equivalent to creating a hole).

But this requires extremely fine

RIKEN researchers have used the gold tip of a scanning tunneling microscope (inverted pyramid) and a terahertz pulse (white squiggle) to create an exciton in a single molecule (X-shaped structure).

control both in time and space. "These two processes—electron injection and extraction—are fundamentally opposite in nature and require precise timing," says Kim. "Controlling these two opposing processes in an ultrafast and precise manner is extremely challenging, especially at the single-molecule level."

Now, Kim and Kensuke Kimura, also of SISL, and co-workers have pulled off this challenging feat, demonstrating the ability to create an exciton on demand in a single molecule.

"Being able to trigger exciton formation on demand and within a picosecond timescale represents a significant breakthrough in ultrafast molecular control," notes Kimura.

To form an exciton in a molecule, the team used a specially shaped laser pulse in the terahertz region—the section of electromagnetic waves sandwiched between microwaves and infrared radiation (see image). They confirmed the creation of the exciton by measuring the light given off when the exciton decayed.

The demonstration opens up exciting possibilities for future exploration.

"This method achieves picosecond temporal and atomic-scale spatial resolution, enabling real-time, real-space investigation of ultrafast quantum phenomena," says Kim.

It could also help to develop next-generation quantum

optoelectronic devices. "The ability to manipulate quantum states in single molecules on demand could lead to breakthroughs in nanoscale quantum light sources, single-molecule photon emitters, and molecular-scale quantum logic gates," adds Kimura. ●

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MOLECULAR SPECTROSCOPY

How a triatomic molecule releases excess energy

A simple molecular ion, consisting of three atoms, exhibits complex cooling dynamics when excited

A resonance effect can significantly affect how a three-atom molecule cools down when excited, RIKEN physicists have found[1]. This highlights the complexity of the relaxation dynamics of even simple molecules.

Small, energetic molecules in a vacuum—such as those in the upper atmosphere or interstellar space—can either break apart or cool down by releasing their energy through emitting light.

"The energy-dissipation mechanism of molecules via radiative cooling is crucial to understanding the stability of hot, excited molecules," says Toshiyuki Azuma of the RIKEN Atomic, Molecular and Optical Physics Laboratory. "It's essential in chemical reactions in dilute environments such as the Earth's upper atmosphere."
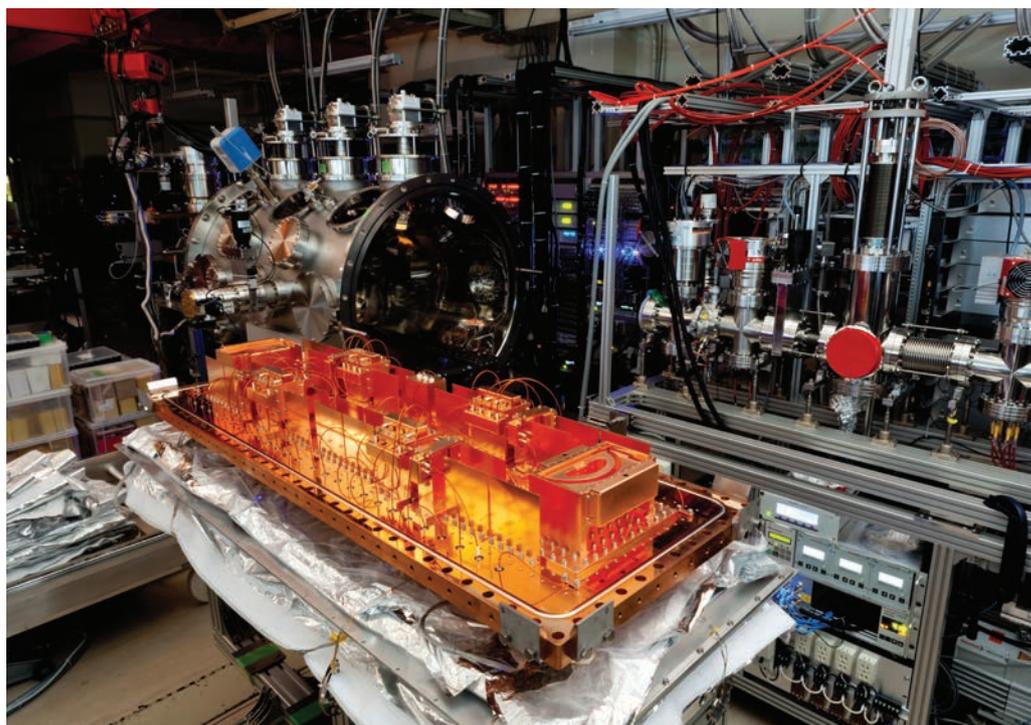
But determining the cooling dynamics of excited molecules can be difficult.

On paper, the positive ion N_2O^+ appears deceptively simple. It consists of two nitrogen atoms connected to an oxygen atom, with all three atoms aligned in a straight line.

And when excited vibrationally, N_2O^+ moves in one of three ways—bending about its central nitrogen atom or stretching along its axis (along the nitrogen–oxygen bond or the nitrogen–nitrogen one).

Naively, its excess energy might be expected to be released in each mode independently. But its cooling process turns out to be surprisingly complex.

Performing measurements is challenging—the molecules need to be in an ultrahigh

The cryogenic ion storage ring at RIKEN (pictured here in parts) is used to measure the relaxation dynamics of N_2O^+.

vacuum and at a temperature within 10 degrees Celsius of absolute zero. And the cooling process occurs over seconds, an extremely long time for molecular spectroscopy by electronic transitions, where transitions usually happen in tiny fractions of a second.

Now, Azuma, Sakumi Harayama, Susumu Kuma and co-workers have used RIKEN's cryogenic ion storage ring (see image)—one of only three such instruments in the world—to determine how N_2O^+ cools after excitation.

One of the stretching movements of N_2O^+ has a similar energy and symmetry as the specific bending movement. This enables the two modes of

vibrational movements to couple via a phenomenon known as Fermi resonance, opening up cooling pathways via vibrational transitions that would not normally occur.

The team thus wondered if Fermi resonance might influence the radiative cooling dynamics of the molecule.

To find out, they exploited the fact that N_2O^+ has two electronic ground states, one with Fermi resonance and one without. This allowed them to directly compare the cooling behaviors with and without Fermi resonance.
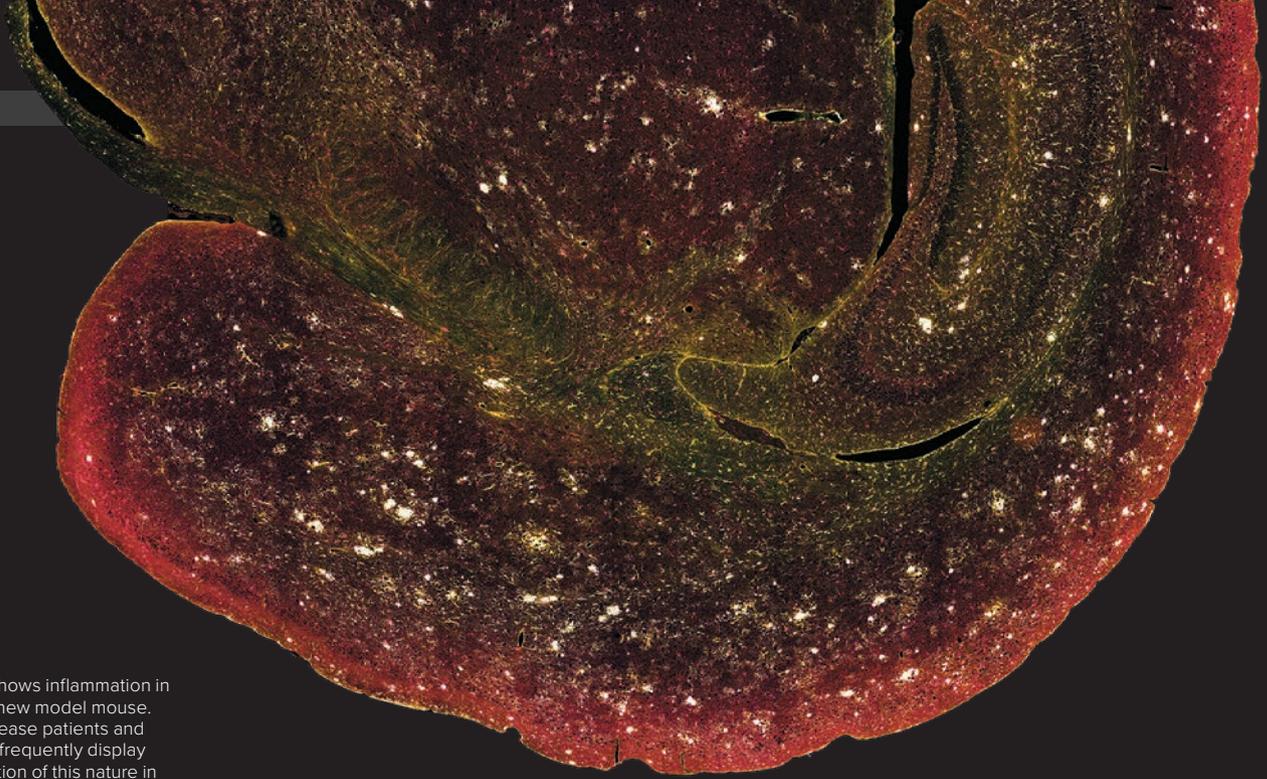
They found that the state with Fermi resonance coupling had a considerably slower cooling rate than the one without it. This was

the first time that the effect of coupling on cooling dynamics had been measured.

"This was the first observation of Fermi resonance in the time domain, showing clear evidence that Fermi resonance plays a crucial role in the vibrational cooling dynamics of molecules," notes Harayama. ●

Reference
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A micrograph shows inflammation in the cortex of a new model mouse. Alzheimer's disease patients and mouse models frequently display neuroinflammation of this nature in association with amyloid pathology.

ALZHEIMER'S DISEASE

Revealing how a natural mutation protects against Alzheimer's disease

A new model mouse for the neurodegenerative disorder has helped uncover the protective mechanism of a genetic mutation

RIKEN researchers have demonstrated the protective effects of a genetic mutation against Alzheimer's disease in animals for the first time[1]. This could eventually lead to the development of new ways to treat the neurodegenerative disorder.

Genetic mutations generally increase the risk of developing diseases. For example, a mutation known as the Swedish mutation is associated with a hereditary form of Alzheimer's disease.

But sometimes mutations can offer protection against diseases. A case in point is a mutation discovered in humans in 2012 that reduces the risk of developing Alzheimer's disease. Named the Icelandic mutation, it is particularly prevalent among Icelanders and was first identified there.

Both the Swedish and Icelandic mutations occur in the same gene—one that encodes for the amyloid precursor protein (APP). When cleaved by certain enzymes, APP can give rise to plaques of beta amyloid in the brain that are a key characteristic of Alzheimer's disease.

Until now, experimental evidence demonstrating the protective effect of the Icelandic mutation had been observed only in lab experiments that did not involve animals.

That may be because most mouse models of Alzheimer's disease harbor the Swedish mutation. This has so far hindered efforts to study the beneficial effects of the Icelandic mutation.

Now, by introducing the Icelandic mutation into an Alzheimer's disease mouse model that lacked the Swedish mutation, a team led by Hiroki Sasaguri of the RIKEN Center for Brain Science has shown the protective effects of the Icelandic mutation in mice.

"This model is important because it is the first in the world to demonstrate the protective effect of the Icelandic mutation against amyloid pathology in animals," says Sasaguri.

Using their new mouse model, the team discovered how the Icelandic mutation protects mice against Alzheimer's disease. Specifically, they found that the Icelandic mutation decreases the susceptibility of APP to be cleaved by the enzyme BACE1, thus reducing the amount of beta amyloid produced in the brains of mice. Thanks to the Icelandic mutation, these mice experienced reduced buildup of beta amyloid plaques compared to mice not carrying the mutation.

The team is now looking into other protective mutations. "We've been searching for and discovering even more powerful protective mutations," says Sasaguri. "We aim to introduce these protective mutations into the animal models using genome editing technology and establish them as a new gene therapy."

The ultimate goal is to develop novel human therapies for Alzheimer's disease. "We're working to elucidate the protective mechanisms involved in order to explore safer and cheaper treatment methods other than genome editing," says Sasaguri. ●
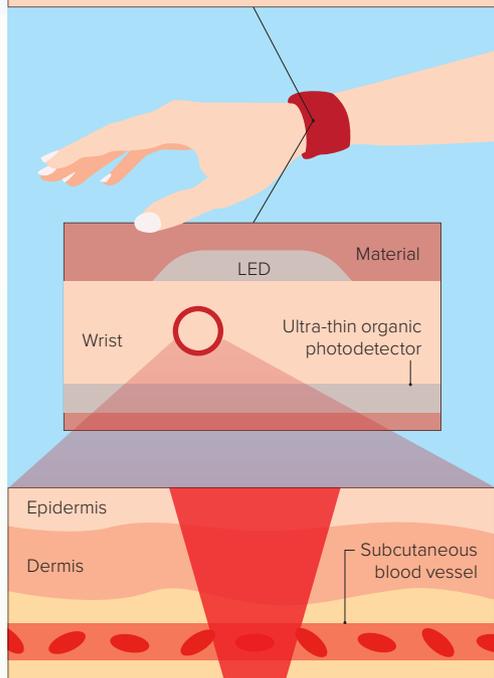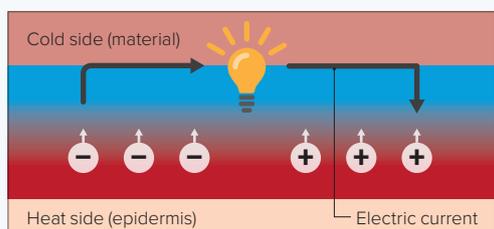
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EMBRACING WEAR AND TEAR

RIKEN researchers have developed unusual materials that are biodegradable, energy-harvesting, self-healing and smart, but washable—hoping to one day help reduce the environmental impact of consumer products.
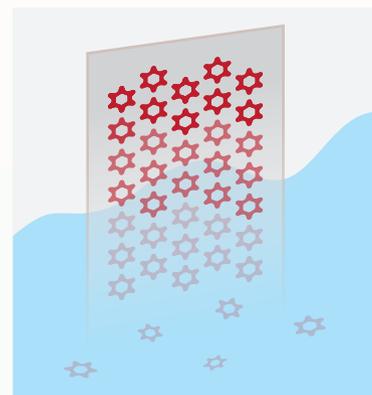
HEAT-POWERED PLASTIC DEVICES

In 2020, a RIKEN-developed thermoelectric polymer was found to convert body heat into electricity very efficiently.[1] Materials of this nature could one-day supplement the battery power of wearable devices, such as health-monitors.

Cold side (material)

Heat side (epidermis) — Electric current

Material

LED

Wrist

Ultra-thin organic photodetector

Epidermis

Dermis

Subcutaneous blood vessel

PULSE MONITORS MADE USING WATERPROOF, FLEXIBLE LIGHT DETECTORS

A RIKEN-designed organic photodetector described in 2024 detects tiny fluctuations in light intensity caused by blood vessel movement as the heart beats. More flexible, biocompatible and potentially cheaper to produce than the inorganic detectors found in the health monitors today, it's also uniquely water-resistant—ideal for skin-contact pulse trackers for swimmers or intense workouts.[2]

OCEAN-DEGRADABLE PLASTIC BOTTLES

To tackle the problem of marine pollution breaking down into microplastics—which can harm human health when ingested by fish—scientists at RIKEN have developed an ocean-degradable plastic made from a supramolecular polymer[3]. The RIKEN polymer's molecules are fortified by strong non-covalent, cross-linked bonds that are only reversed by the introduction of salt. The material is thus mechanically strong, enabling durable goods—such as bottles or packaging—that break down in sea water.

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WASHABLE SOLAR POWER
An organic photovoltaic film on a stretchable, water-resistant substrate and a semiconducting polymer blend was developed by researchers at RIKEN and the University of Tokyo in 2024. These solar cells maintain roughly 90–95% of their power conversion efficiency even after hours of water immersion and tests of underwater stretching.[4] If integrated into textiles, the cells could provide washable, flexible solar power for sustainable outdoor adventures.

Cathode   Emissive layer

Anode

Substrate   Conductive layer

SELF-HEALING LIGHT-EMITTING SAFETY GEAR
A self-healing emissive polymer developed in 2024 emits strong fluorescence under UV light and self-heals microcracks[5], making it ideal for wearable lighting or safety gear that can function even after some abrasion damage.

Research domains for demonstrating outstanding **scientific research** and comprehensive capabilities

To leverage RIKEN's comprehensive capabilities and to conduct more effective management with a stronger strategic focus, a new system was introduced in fiscal year 2025. It consists of five research domains—Pioneering Science; Mathematical, Computational and Information Science; Life Science; Sustainability Science; and Physical Science.

Each research domain is led by an Executive Director of Science (right), an internationally outstanding scientist who possesses extremely high expertise both academically and in research management. These Executive Directors of Science encourage cross-disciplinary collaboration based on advanced specialized knowledge, accelerating the creation of new knowledge. Supporting research promotion are the Promotion Division Directors (also right). We have asked about the goals of each domain from both researchers' and administrative departments' perspectives. ➜

Here we feature two domains and a sixth, unifying group, TRIP. Find out more on p27.

RIKEN's Executive Directors of Science, together with the Division Directors from the five research fields of Pioneering Science, Mathematical, Computational and Information Science, Life Science, Sustainability Science, and Physical Science, as well as the Director and Division Director of the Transformative Research Innovation Platform of RIKEN platforms (TRIP), gathered together in one place.

RIKEN'S ORGANIZATION

PIONEERING SCIENCE DOMAIN

This domain aims to contribute to the dramatic advancement of science and technology and the creation of new value; to international brain circulation through the creation of networks with top-class research institutions and researchers; and, to the training of outstanding young researchers.

MATHEMATICAL, COMPUTATIONAL AND INFORMATION SCIENCE DOMAIN

This domain aims to organically connect researchers in different fields and create the computational infrastructure and fundamental principles needed for the promotion of future science, technology and social change.

LIFE SCIENCE DOMAIN

This domain aims to approach the essence and totality of life, spanning different levels, time axes, and species, and the span of mechanisms of complex life, including genomes, epigenomics, and environmental factors.

SUSTAINABILITY SCIENCE DOMAIN

This domain aims to build a sustainable society by safeguarding the Global Commons and achieving both human and planetary health. Its research focuses on the development of biological resources and bioproduction, material circulation, and symbiosis with the environment.

PHYSICAL SCIENCE DOMAIN

This domain aims to bring together diverse researchers and develop information processing technology and highly efficient energy-conversion technology through cross-disciplinary research and discussion, with the goal of solving social issues such as the realization of Society 5.0 and creating new academic disciplines.

KAZUKI SAITO

Executive Director of Science, Sustainability Science Domain

PROTECTING THE HEALTH OF PEOPLE AND THE PLANET

As human activities have grown to an unprecedented scale, the Earth is now approaching or even exceeding several of the thresholds known as 'planetary boundaries'. Planetary boundaries refer to the limits that humanity must not surpass in order to sustainably survive on Earth. If current trends continue, it will become increasingly difficult to maintain the health and survival of both the planet and humankind.

Our mission in the field of sustainability science is to harness the power of science and technology to protect the global commons—Earth's systems shared by all of humanity—and to achieve a balance between the health of people and the planet.

OUR GOAL: SUSTAINING SUSTAINABILITY

A defining feature of the sustainability science domain is that it not only refers to an academic discipline, but also clearly presents a goal: the maintenance of sustainability. This clarity of purpose allows researchers from diverse specialties to align their efforts toward a common objective, fostering a powerful sense of unity that drives collaborative, interdisciplinary research.

This domain comprises all research groups within the RIKEN Center for Sustainable Resource Science (CSRS) and selected groups within the RIKEN BioResource Research Center (BRC) that focus on plants and microorganisms. Over 30 principal investigators lead their respective teams, conducting highly advanced and cutting-edge research.

Our research is centered on plant science, catalytic chemistry, and chemical biology, with a focus on building a sustainable future. Enhancing the productivity and functionality of plants and microorganisms plays a key role in stabilizing our food supply and creating a society with reduced dependence on fossil resources. Meanwhile, the development of highly efficient catalysts and innovative polymer materials contributes to building a resource-circulating society that minimizes consumption and waste. Additionally, by elucidating the symbiotic relationships between plants and microorganisms, we are working toward the low-impact production of agricultural products and useful substances.

One key research theme is the development of plants resistant to environmental changes brought about by climate change. For example, a technique using ethanol treatment to improve drought tolerance has shown promising effects on major crops such as wheat, rice, cassava, tomato, and lettuce, with practical applications expected in the field.

CSRS also boasts world-class research infrastructure, including metabolomics and multi-omics analysis platforms, diversity genome analysis, and a comprehensive compound library. In parallel, BRC contributes its extensive bioresource collections—plants, microorganisms, and more—essential for biodiversity conservation and reliable research, strengthening the overall field.

As the Executive Director of Science of this research domain, I see my role as creating an environment where researchers can fully pursue their intellectual curiosity, while ensuring that their scientific achievements ultimately contribute to

society. In addition to securing essential resources such as time for research and funding, I also place great importance on promoting active dialogue across disciplines and institutions, both domestically and internationally, to foster new ideas.

For researchers, having their curiosity-driven work recognized is a source of immense satisfaction—but when their research is actually implemented in society to benefit others, I believe that joy is multiplied many times over.

TOWARD THE REALIZATION OF PLANETARY HEALTH

The year 2030—the target set by the United Nations for achieving the Sustainable Development Goals (SDGs)—is fast approaching. In the sustainability science domain, we are committed to conducting responsible research that skillfully balances urgent, short-term challenges with long-term research and development that looks 10 or even 20 years into the future.

Our ultimate goal is the realization of 'planetary health'—a balance between the health of people and the planet. Through this, we aim to protect both human and environmental well-being, build a safer and more equitable society through the power of science, and contribute to paving the way toward a sustainable future. ●

RYOSUKE MARUYAMA

Division Director, Sustainability Science Promotion Division

In the sustainability science domain, social implementation that leads to real-world solutions is particularly important. To this end, we place strong emphasis on coordination with research institutions in fields such as the humanities, social sciences, and economics, aiming to bridge scientific innovation with societal impact.

PURSUING A DEEPER UNDERSTANDING OF MATTER, LIGHT, AND QUANTUM PHENOMENA

When people hear the term 'physical sciences', they tend to think of physics alone. However, the physical sciences encompass a much broader academic field, which includes not just physics, but also chemistry, engineering, and other disciplines outside of the life sciences.

Our domain of physical sciences consists of four distinctive research centers, each with a unique character.

YOSHINORI TOKURA

Executive Director of Science, Physical Science Domain

The RIKEN Center for Emergent Matter Science (CEMS), where I served as the inaugural director, is dedicated to exploring the properties of matter and creating new materials and functions. Since its inception, we have built a system that enables world-class achievements through collaboration.

The RIKEN Center for Advanced Photonics (RAP) produces groundbreaking research that leads the world, including astonishing innovations such as the optical lattice clock and attosecond lasers.

The RIKEN Nishina Center for Accelerator-Based Science (RNC) is centered around the RI Beam Factory, a massive accelerator facility. The entire center works together as one to lead the global field of nuclear physics.

The RIKEN SPring-8 Center (RSC) is one of the world's largest synchrotron radiation facilities, providing collaborative research opportunities to scientists from a wide range of fields both in Japan and internationally.

Our goal is to maximize the potential of each center—each with a different origin and culture—and to foster new interdisciplinary fields through close collaboration between them.

AKIHIKO TANAKA

Division Director, Physical Science Promotion Division

Before assuming this position, I was involved in mid- to long-term planning in the Policy Coordination and Management Division. I am now very excited to work more closely with the research frontlines in this Promotion Division. Under the leadership of Prof. Tokura, I hope to help elevate the science promoted by the Physical Sciences Domain and support researchers as they take on new challenges for the future of RIKEN and society.

'WIN–WIN' COLLABORATION AND OPPORTUNITIES FOR ENCOUNTERS

When researchers collaborate, a 'win–win' relationship is essential. Rather than forcing top-down collaboration from a project leader, it is crucial for researchers themselves to recognize the benefits of working together and to take the initiative in doing so.

However, many researchers in Japan are somewhat shy, and as a result, collaborative efforts are not as common as they are abroad. That's why we actively host workshops, symposiums, and research meetings—to create opportunities for researchers to meet and connect.

The driving force behind research is the curiosity of each individual scientist. We aim to respect their free thinking and original ideas to the fullest, and to support the further development of those ideas.

Helping researchers discover the hidden value of their work—value they may not even be aware of—is also one of the important roles of our field. Former RIKEN President Ryoji Noyori once said: "The most important thing in science is the discovery of value." This couldn't be more true. Just as the discovery of a new synthetic pathway can lead to new drug development, even basic research that seems modest at first may hold the power to transform society.

CONTRIBUTING TO FUTURE SOCIETY—THE VISION OF PHYSICAL SCIENCES

Research in the physical sciences may seem distant from everyday life. However, it is deeply connected to solving major societal challenges—such as realizing 'Society 5.0', which involves a seamless integration of virtual and physical spaces, and tackling global-scale energy problems.

For example, breakthroughs born from basic research—such as new electronics technologies that enable advanced information processing with reduced energy, or innovative new materials with minimal environmental impact (see page 22)—have the potential to make future society more prosperous and sustainable.

By bringing together researchers with diverse strengths and perspectives, we are committed to contributing to the advancement of future society. ●

FANTASTIC FIVE

RIKEN has five new research domains. In this issue of *RIKEN Research* we cover two: Sustainability Science and Physical Science. You can find out more about the Pioneering Science; Mathematical, Computational and Information Science; and Life Science domains in the Summer 2025 issue or online via the QR codes below.

PIONEERING SCIENCE DOMAIN

SCIENCE, MATHEMATICAL, COMPUTATIONAL AND INFORMATION SCIENCE DOMAIN

LIFE SCIENCE DOMAIN

NATION-BUILDING THROUGH SCIENCE

At TRIP Headquarters, officially known as the Transformative Research Innovation Platform of RIKEN platforms, our mission can be simply summarized as 'science that connects'.

The natural sciences encompass a wide range of fields, and at RIKEN—Japan's only comprehensive research institute for the natural sciences—cutting-edge research is being conducted rather independently in many of these research fields. However, there has traditionally been a lack of strong interdisciplinary collaboration. When President Gonokami assumed the presidency three years ago, he proposed an initiative that would capitalize on RIKEN's unique strengths by connecting different scientific fields through common threads such as data science, mathematical computation, and artificial intelligence (AI).

AI AND HYBRID COMPUTERS AS TOOLS FOR COLLABORATION

RIKEN is not only home to the supercomputer Fugaku, but is also actively conducting research in quantum computing. Combining the strengths of both into hybrid computing systems may one day enable us to make near-future predictions. This idea has resonated deeply with researchers across various fields. In other words, through the accumulation of high-quality data, the expansion of computational possibilities using hybrid computers, and the integration of AI and hybrid computing through mathematical sciences, we are able to connect disparate research domains.

I myself have worked on research related to how to use quantum computers. Quantum computers excel at finding the best solution from a multitude of possibilities, a characteristic they share with AI. Mathematical science bridges AI and computing, seeking to explain complex phenomena using equations. On the other hand, it is difficult to express phenomena in the life sciences through equations, and researchers often rely heavily on image data due to the vast amounts of information involved. At first glance, mathematical science and life science might appear to have little in common.

Yet in modern medicine, AI is already being trained on endoscopic images to identify characteristics of cancer and assist physicians in diagnosis. The combination of AI and computing is proving effective not only in life sciences but also in particle physics and many other areas. Even if disciplines appear distant, the right collaborative tools can bring them together.

ATTRACTIVE RESEARCH THEMES IN THE GAPS BETWEEN FIELDS

Given the nature of specialization in research, a certain degree of compartmentalization is inevitable. I'm not trying to forcefully dismantle those silos. Rather, I believe that the most compelling research themes often lie in the gaps between them. The ideas that leak through those gaps can eventually merge into something larger. When the notion that there's something intriguing in these spaces resonates with researchers, others around them are encouraged to start looking for those gaps as well.

At the TRIP Headquarters, we hold monthly online meetings involving researchers from various fields. When someone shares a current research challenge, four or five people quickly offer suggestions or advice. Principal investigators often encourage junior researchers to join by saying, "Dr. X will be attending the next meeting—you might find it useful for your work." Even across vastly different disciplines, valuable insights emerge. In this way, silos can actually be leveraged rather than eliminated.

These kinds of 'connections' are a strength

of TRIP, but at first, we used computational science and digital transformation as tools to connect researchers. Today, new research themes have emerged that transcend individual research centers—areas like AI for science, fundamental quantum science, and advanced semiconductor science. These are areas difficult to pursue within the existing organizational structure, but possible through cross-disciplinary collaboration. The smooth progress of these new projects is proof that data integration, AI, mathematical sciences, and hybrid computing are powerful enablers of collaboration.

Young researchers, in particular, are acutely aware of this. They know that if they don't try something different, they will not be able to surpass their mentors. And if researchers cannot surpass the previous generation, science cannot move forward. Today, AI, mathematical sciences, and hybrid computing are our tools. But, in five years, new technologies will take their place. One of TRIP's strengths is its flexible and evolving structure: once a research theme is proposed, researchers naturally gather around it.

Global challenges such as climate change, energy shortages, and food insecurity won't be solved by the sudden appearance of a lone superstar. Researchers must find the intersection between their personal interests and broader societal issues. By aligning what they want to do with what society needs from science, they can take pride in knowing their research is making a real-world impact.

A RARE AND SERIOUS EFFORT BY TOP RESEARCHERS

In this light, I see the TRIP Headquarters' motto as 'Nation-building through science'. By utilizing RIKEN's cutting-edge research platforms, we aim to lay the foundation for new research and generate new knowledge—not only for Japan, but for the enrichment of humanity as a whole. There are few instances of institutions in the world as large as RIKEN having top researchers so seriously dedicated to the idea of 'science that connects'.

The world faces major challenges, but our children, grandchildren, and future generations deserve to live full lives, to enjoy their work and their time on this planet. We hope to contribute to building a peaceful and sustainable society through science. ●

Director, TRIP Headquarters

MASASHI KAWASAKI

SCIENCE THAT CONNECTS

The TRIP initiative was launched in 2022 as an effort designed to address scientific and societal challenges that are difficult to solve within the scope of a single research field, by promoting cross-disciplinary collaboration.

At the core of this initiative lies the TRIP concept (Transformative Research Innovation Platform of RIKEN platforms), proposed by President Gonokami. The goal is to organically integrate RIKEN's cutting-edge platforms across various research domains and realize 'science that connects'.

Several programs are already underway, including the Data and Computational Sciences Integration Research Program (CoRe) and the Advanced General Intelligence for Science Program (AGIS).

Driven by fundamental science, TRIP aims to contribute to solving global-scale challenges such as the preservation of the global commons, to promote social transformation for Japan's economic growth, to create a sustainable future, and to support the advancement of human society as a whole.

KAZUSHIGE FUKUSHIMA

Division Director, TRIP Promotion Division

Human society and civilization now stand at a major crossroads, faced with challenges such as global warming and environmental destruction. Under the leadership of Director Kawasaki, a leading figure in the fields of physics and engineering, RIKEN has embraced the vision of nation-building through science. By working alongside the world's top researchers, we aim to help shape a future society centered on new science and technology as a winning strategy for Japan. To this end, we hope to advance our initiatives through 'science that connects' that bridges research domains and fosters interdisciplinary collaboration.

PROGRAMMING PLANTS
TO FIGHT PATHOGENS

A gene from pomelo trees helps plants detect pathogens by recognizing cold-shock proteins. This offers a promising path to engineer crop immunity and reduce pesticide use in agriculture. This discovery could revolutionize how we protect plants from disease.

By studying molecules that detect pathogens in plants, scientists have figured out how to customize them to target specific pathogens

This feature looks at the work of **BRUNO POK MAN NGOU**

After graduating with a degree in biology from Imperial College London, Ngou obtained his PhD degree from The Sainsbury Laboratory, University of East Anglia in Norwich, United Kingdom. He moved to Japan in 2021 and is now a special postdoctoral researcher at the RIKEN Center for Sustainable Resource Science. He is now working on the identification of new immune receptors in diverse plant species.

Modern agriculture uses enormous quantities of pesticides and fungicides, which can negatively impact the environment and people. Finding ways to boost the immune responses of plants against pathogens could help us use fewer chemicals on farms.

RIKEN researchers have discovered a key component of plant immunity that could unlock the possibility of programming their immune response to target specific pathogens, including economically important pests[1].

But the RIKEN team wasn't initially thinking of engineering the immune responses of plants.

"When we started, we wanted to characterize the immune receptors that are unique to each plant species," says Bruno Pok Man Ngou, a postdoctoral researcher at the RIKEN Center for Sustainable Resource Science.

Since immune receptors vary a lot between species, Ngou was interested in studying diverse plant species in addition to the usual model species used in labs. "I started with the idea that we can discover new things in the plants that we see outside all the time," he says.

The team focused on a specific class of immune receptors, the proteins that recognize and bind to molecules from pathogens and activate the immune response.

For a plant to mount an immune response to a pathogen, the first, crucial step is detecting the pathogen. "That's the immune receptor's job," says Ngou.

The team surveyed the genomes of 350 plant species and found more than 13,000 genes that code for immune receptors. They grouped the receptors into clusters based on which molecules they bound, then selected 210 genes from relatively large subgroups. These represented a significant fraction of the receptors.

The researchers then screened those genes to determine those that encode for immune receptors that bind to *Agrobacterium tumefaciens*, the bacterium that causes crown gall disease. Seven of the genes did, and the team selected one of them—a gene from the tree of the citrus fruit pomelo—for further investigation.

GETTING SPECIFIC

Having found a gene that codes for the receptor that binds to molecules from the crown gall bacterium, the team set out to understand how it recognizes those molecules.

First, they had to identify the molecule it recognized, which turned out to be a cold-shock protein—a protein involved in imparting tolerance to the cold and is found in bacteria, fungi, plants and animals.

Next, they sought to discover how the receptor recognizes the cold-shock protein. By comparing this receptor with another that also binds to a cold-shock protein, the researchers identified the region of the proteins that the receptors specifically recognized. Further experiments revealed the key sites in that region that are specific to each species—that is, how receptors recognize cold-shock proteins from specific pathogens.

"Those positions can be unique to a specific organism," explains Ngou. "Each pathogen will have a combination of specific signatures there. It could be specific to a particular pathogen or to a class of pathogens, which makes it a pretty good target."
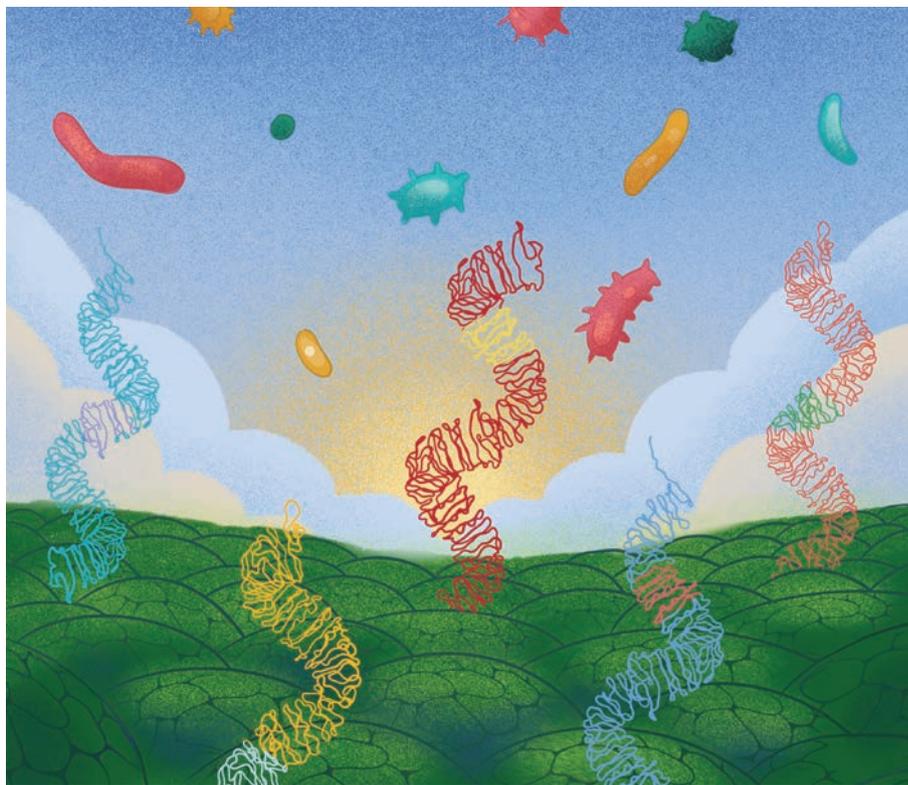
Based on this, the team determined the precise mechanism by which the receptor recognizes and binds to the cold-shock protein.

This discovery unlocked an unexpected ability: custom designing a receptor that recognizes molecules from a specific pathogen.

The researchers looked for pathogens that are economically threatening and that have cold-shock proteins. They engineered a version of the receptor that recognizes cold-shock proteins from root-knot nematodes and several pathogenic bacteria. Another engineered version responds to molecules from filamentous soil fungi and false smut fungi, as well as from certain pathogenic bacteria.

FIELD TRIALS

While the technology is exciting, the

The immune receptors of plants, pictured in this illustration, could be engineered to help reduce pesticide use by helping plants target specific pathogens, such as bacteria, fungi or nematodes.

researchers haven't yet gone any further than molecular experiments in the lab. The next step is to test how effective the technology is in plants. The researchers also need to figure out how strongly the gene should be expressed: too little and it won't help the plant, too strongly and it could lead to autoimmunity or other yield-reducing side-effects.

"There's a very fine balance between how many immune receptors there should be, how strongly they should be expressed and where they should be expressed," says Ngou. "There are many considerations and also a lot of field-related work that goes into testing the best way to roll something like this out."

The researchers aren't limiting themselves to working with this receptor; they're planning to repeat the screen with molecules from other pathogens to find and characterize new receptors.

"We want to try screens with as many pathogens as possible," says Ngou. "We want to test other pathogenic bacteria, fungi and even insects. Provided we can get an extract from the organism, we can do the

screening."

They're also working to expand their library so that they can cast a broader net, in keeping with Ngou's original motivation. "There are many unknown receptors out there," he says. "The more scientists know about them, the more they can be used to help protect crops."

In the long term, the team hopes to catalog as many receptors as possible, targeting different types of molecules and covering different pathogens. These could be used to engineer plants to recognize pathogens they haven't evolved resistance against, which could reduce the need for pesticides.

"The end goal is to provide the crops with a better immune sensing system," says Ngou. ●

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RIKEN'S CENTERS AND FACILITIES

*Denotes large research infrastructure

SENDAI
- Center for Advanced Photonics (RAP)

KOBE
- Center for Biosystems Dynamics Research (BDR)
- Center for Computational Science (R-CCS)
- Data and Computational Sciences Integration Research Program (CoRe)
- Advanced General Intelligence for Science Program (AGIS)
- Baton Zone Program (BZP)
- Pioneering Research Institute (PRI)
- Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)
- Animal facility*
- Robotic Biology Prototyping Laboratory*
- Supercomputer MDGRAPE-4A*
- Supercomputer Fugaku*

WAKO
- TRIP Headquarters
- Data and Computational Sciences Integration Research Program (CoRe)
- Advanced General Intelligence for Science Program (AGIS)
- Fundamental Quantum Science Program (FQSP)
- Program for Drug Discovery and Medical Technology Platforms (DMP)
- Advanced Semiconductor Science Program (ASSP)
- Industrial Co-creation Program (ICoP)
- Baton Zone Program (BZP)
- Pioneering Research Institute (PRI)
- Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)
- Center for Computational Science (R-CCS)
- Center for Quantum Computing (RQC)
- Information R&D and Strategy Headquarters (R-IH)
- Center for Brain Science (CBS)
- Center for Sustainable Resource Science (CSRS)
- Center for Emergent Matter Science (CEMS)
- Center for Advanced Photonics (RAP)
- Nishina Center for Accelerator-Based Science (RNC)
- SPring-8 Center (RSC)
- Administrative Offices
- Radio Isotope Beam Factory (RIBF)*

TSUKUBA
- BioResource Research Center (BRC)
- Center for Sustainable Resource Science (CSRS)
- Bioresources*

TOKYO
- Center for Advanced Intelligence Project (AIP)
- Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)
- Center for Computational Science (R-CCS)

YOKOHAMA
- Center for Integrative Medical Sciences (IMS)
- Center for Sustainable Resource Science (CSRS)
- Program for Drug Discovery and Medical Technology Platforms (DMP)
- Baton Zone Program (BZP)
- Pioneering Research Institute (PRI)
- Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)
- Center for Computational Science (R-CCS)
- Genome Sequencing*
- Nuclear Magnetic Resonance (NMR)*
- Cryo-electron microscope*

HARIMA
- SPring-8 Center (RSC)
- SPring-8*
- SACLA*

KEIHANNA
- BioResource Research Center (BRC)
- Center for Advanced Intelligence Project (AIP)
- Information R&D and Strategy Headquarters, Guardian Robot Project (GRP)

In addition to five main campuses in Japan, RIKEN has facilities in the United States and joint research centers or laboratories in Germany, Italy, Luxembourg, Malaysia, the United Kingdom, the United States, and Vietnam. It also has liaison offices in Singapore, Beijing, and Brussels.

For more information, please visit:
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