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RESEARCH

SUMMER 2025

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GUT REACTION

Caterpillars synthesize new materials

QUANTUM POWER-UP
Ushering in a new era of batteries

MOB MENTALITY
Human brain wired for teamwork

EMOTIONAL ENCODING
How sleep makes good memories stick

FAT BUSTER
Mice that had *Bacteroides* sp. (pictured) in their guts generated more energy from burning liver fat and less from burning carbohydrates when they were given an acetate supplement than mice fed a normal diet, meaning they lost weight without losing muscle mass (see page 11).

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.

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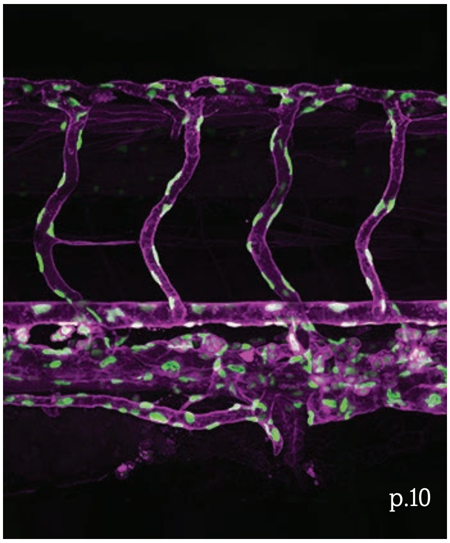

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To our readers

Makoto Gonokami
President, RIKEN

For over a century, humanity has made remarkable strides in science and technology, driving societal growth. But we face serious global challenges that threaten our very future—global warming, environmental destruction, economic disparities, and roadblocks to international collaboration. We have also seen the rapid evolution of digital technologies. Most recently, this is being driven through innovations in generative AI, leading to major social changes that we expect to continue as quantum computing takes off.

In April this year, RIKEN embarked on our fifth Mid-to-Long-Term Plan, and under it we will lead society in building a better future through the following actions. First, based on a precise assessment of the latest trends in frontline research, we have adopted a research structure with five domains—Pioneering Science; Mathematical, Computational and Information Science; Life Science; Sustainability Science; and Physical Science—with the aim to create new knowledge in an interdisciplinary manner.

Second, to further encourage collaboration across the five research domains, the TRIP (Transformative Research Innovation Platform of RIKEN platforms) initiative is being expanded, further bolstering its data-driven approach.

Third, we are currently developing a next-generation HPC infrastructure called FugakuNEXT, as well as a fourth-generation synchrotron radiation facility called SPring-8-II. We are also working to build a sustainable research environment by limiting CO_2 emissions and ensuring that research facilities are efficiently shared by researchers, both inside and outside RIKEN.

Fourth, to better foster next-generation researchers, we are strengthening the RIKEN Early Career Leaders Program, actively hiring and promoting women scientists and international researchers, as well as exchanging research personnel with universities and other institutions.

Finally, we are ensuring that our activities are in step with our vision of a better future. As we help enrich the future and the lives of the people who will live in it, we hope that our efforts will increase the trust that society has in science.

COVER STORY: RIKEN scientists have been able to transform carbon nanomaterials by feeding them to caterpillars. *Page 30.*

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Tracing our ancestors' genomic footprints

Leo Speidel
Unit Leader, Mathematical Genomics Early Career Leaders Research Unit
RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)

Please describe your current research.

My work aims to understand the evolutionary forces that have shaped human genetic differences and how these may impact our health. Excitingly, we can now look back many hundreds of millennia into the past by extracting DNA from ancient bones and applying new statistical techniques that reconstruct the genetic trees that relate these people back in time.

Using these techniques, my team can reveal historical events in unprecedented detail by demonstrating how these have impacted the genomes of our ancestors. Our work has identified population bottlenecks and expansions, mixtures and migrations of human groups over millennia and adaptations to dramatic changes in climate, lifestyle and pathogens.

From this, we can show the evolutionary trajectory of mutations that cause disease and can also reveal more about the molecular machinery that introduces this variation through the generations.

Please describe your role.

I'm a unit leader at RIKEN's Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS). I joined RIKEN in November 2024 as part of the Early Career Leaders program, which supports junior group leaders as they establish a research group. Before this, I was at University College London in the UK and at the biomedically-focussed Francis Crick Institute. There, I was a Sir Henry Wellcome Fellow, which also aims to support recently qualified postdoctoral researchers as they start independent research careers.

What are some interesting recent discoveries in your field?

When I started my PhD, I was fascinated by a 2015 *Nature* paper that looked at the genetic structure of the people of the UK at very fine scales. It suggested links between this structure and the different historical migrations into the UK, such as the arrival of Anglo-Saxon-related people in the fifth century. It was mind blowing to me to think that such information is still traceable in our DNA. These insights would not be accessible without some recent innovations in the statistical modeling of our DNA differences.

This year, we published a method in *Nature* that has allowed us to pinpoint migration events in Europe using ancient DNA, revealing significant migration events dating back to the first millenium AD in early medieval Europe that were previously unknown.

Among other things, we're working on applying this method to different regions around the world, including Japan.

What RIKEN technologies help you to do your work?

We test our methods on simulations and then apply these to large-scale genetic data, where we rely heavily on high-performance computers, such as RIKEN's Hokusai supercomputer.

What has been your most memorable experience at RIKEN?

I've only been at RIKEN for six months, but my most memorable experience so far has been a recent outreach event aimed at high school students. Our center, iTHEMS, is home to a diverse group of multidisciplinary researchers, who all incorporate mathematics and its applications into their work. In addition to interacting with the students, it was great to hear my colleagues talk and to really understand for the first time what some of them work on! ■

Meet a rising star at RIKEN: Interview with Leo Speidel

Mouse models of the brain breaking down

Tra Thi Huong Dinh
Research and Development Scientist, Next Generation Human Disease Model Research Team
RIKEN BioResource Research Center (BRC)

Describe your role at RIKEN.
I use genome editing technology to develop mouse models of neurodegenerative diseases. Currently, I'm involved in the production of models of amyotrophic lateral sclerosis (ALS), a progressive neurodegenerative disease that affects nerves in the brain and spinal cord.

Briefly describe your current research.
My objective is to establish a streamlined pipeline to investigate the causes and characteristics of ALS. At present, I'm working on expanding my ability to conduct experiments on ALS mouse models, while comparing our results with databases on human ALS pathology.

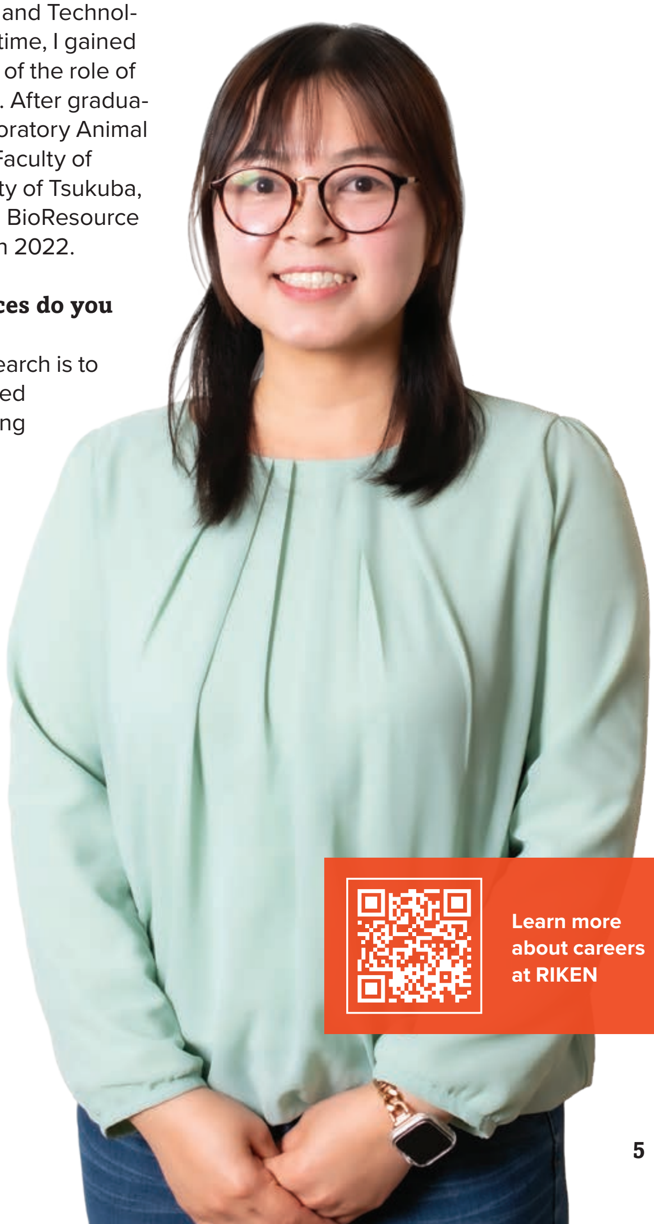
I'm involved in the production of models of a progressive neurodegenerative disease.

How did you become interested in your field?
Before coming to Japan, I graduated from the University of Medicine and Pharmacy in Ho Chi Minh City, Vietnam, majoring in traditional medicine. Afterwards, I worked for two years as a doctor and as a lecturer at the university. Initially, I believed that interacting directly with patients would be more interesting than working in a laboratory. I eventually became aware that research could lead to a cure for patients, which motivated me to switch my focus.

When did you join RIKEN?
I came to Japan to study as part of a PhD program in human biology at the University of Tsukuba, a program for leading graduate schools administered by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT). During this time, I gained a deeper understanding of the role of certain genes in disease. After graduation, I worked at the Laboratory Animal Resource Center in the Faculty of Medicine at the University of Tsukuba, before joining the RIKEN BioResource Research Center (BRC) in 2022.

What RIKEN resources do you use?
The first stage of my research is to create genetically modified mice using genome editing technology based on ALS patient genomes and variant information. Then we look for genetic evidence and observable traits associated with the disease in these mouse models. To understand how the disease manifests in mice, we receive support from the Japan Mouse Clinic at the BRC, which provides information on groups of mouse characteristics, or phenotypes, using more than 700 mouse traits. We then work closely with clinical researchers to harness the most representative mouse models of a disease to evaluate therapeutics and conduct detailed assessments on the causes and consequences of a disease.

How do you balance family life with your work at RIKEN?
My family is one of my most important supports. My three daughters—who were all born in Japan—are now in elementary school and preschool. To refresh ourselves, we spend time sightseeing and going on camping trips. So far, we have been to many places in Japan, from mountainous Gunma prefecture to some of the more coastal parts of Shizuoka prefecture. ■



Learn more about careers at RIKEN

Bulgarian President visits Wako Campus

On May 21, 2025, His Excellency Rumen Radev, the President of the Republic of Bulgaria, visited the RIKEN Wako Campus, accompanied by a delegation of 20 people, including Her Excellency Marieta Arabadjieva, the Bulgarian Ambassador to Japan; His Excellency Hisashi Michigami, the Japanese Ambassador to Bulgaria; and representatives from major universities, research institutions, and companies in Bulgaria.

The visit began with an address from RIKEN Executive Vice President Masashi Kawasaki, followed by an introduction to RIKEN from Makiko Naka, Special Advisor to the President, and an introduction to the RIKEN Center for Quantum Computing (RQC) by Center Deputy Director Shinichi Yorozu. This was followed by discussions on further cooperation between RIKEN and research institutes in Bulgaria.

The delegation was then given a tour of RQC, including the superconducting quantum computer “A”.

www.riken.jp/en/news_pubs/news/2025/20250609_1

His Excellency Rumen Radev (at left) and his party were given a tour of the RIKEN Center for Quantum Computing by Deputy Director Shinichi Yorozu (center).

RIKEN and Fujitsu unveil world-leading 256-qubit quantum computer

RIKEN and technology company Fujitsu Limited have developed a 256-qubit superconducting quantum computer that will significantly expand their joint quantum computing capabilities.

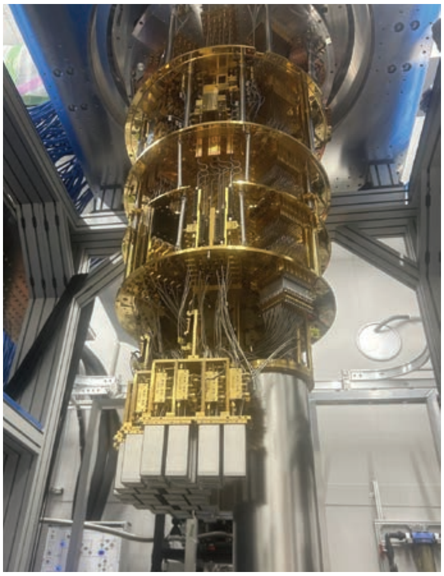
The system, located at the RIKEN RQC–FUJITSU Collaboration Center on the Wako campus, builds upon a 64-qubit iteration, which was launched with the support of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) in October, 2023. The new system incorporates newly developed high-density implementation techniques and overcomes some key technical challenges, including appropriate cooling, which is achieved through clever high-density design and cutting-edge dilution refrigerator innovation.

This is a step toward the use of superconducting quantum computers in solving some of the world’s most complex issues, such as the analysis of large molecules and the implementation of sophisticated error-correction algorithms.

The organizations plan to integrate the new quantum computer into their platform for hybrid quantum computing, allowing it to be used by companies and research institutions globally from the second half of 2025.

Fujitsu and RIKEN will continue to look toward launching a 1,000-qubit computer in 2026.

www.fujitsu.com/global/about/resources/news/press-releases/2025/0422-0



A 256-qubit quantum computer (above) has advanced global hybrid computing capabilities.

Scientists from Universiti Sains Malaysia and RIKEN's Interdisciplinary Collaboration for Advanced Sciences.

Malaysian agreement renewed

On April 9, 2025, a ceremony renewing the USM–RIKEN Interdisciplinary Collaboration for Advanced Sciences (URICAS) agreement was held on RIKEN's Wako campus.

The agreement between Universiti Sains Malaysia (USM) and RIKEN has facilitated joint work and researcher exchange since 1993.

As a result, since 2002, RIKEN has accepted 46 USM students and researchers through the International Program Associate system. A number of collaborative papers have also been published in fields such as biochemistry, material science and chemical engineering. Annual workshops are also held to further facilitate collaboration.

www.riken.jp/en/collab/research/riken_usm

Trillion Parameter Consortium Hackathon

The Trillion Parameter Consortium (TPC) Winter 2025 Hackathon hosted 60 passionate participants from Japan, US, Spain and other countries for three days in March 2025, at the RIKEN Center for Computational Science (R-CCS) in Kobe, Japan. The event was organized by TPC, an emerging collective of companies and national institutions, including the likes of RIKEN and the United States Department of Energy National Laboratories and Technology Centers, interested in the idea of 'AI for Science', the use of artificial intelligence to further scientific endeavor. Currently, more than 90 organizations participate in TPC.

TPC convenes hackathons to bring together individuals and groups who are developing, training and harnessing large-scale models along with those operating the high-performance computing systems necessary for model training. Breakout groups looked at issues such as scientific skills, safety and trust evaluations; model architecture and performance evaluations; and life sciences challenge problems.

This was the first time the hackathon had been held in Japan, and the event was supported by the RIKEN TRIP initiative (AGIS) and R-CCS.

https://tpc.dev/tpc-winter-2025-hackathon/

Osaka to host SCA/HPCAsia 2026

The annual SupercomputingAsia (SCA) conference—co-organized by high-performance computing centers in Singapore, Japan, Australia and Thailand—incorporates a number of notable supercomputing and related events from the region and beyond.

The overarching goal of SCA is to promote a vibrant and shared high-performance computing ecosystem in Asia.

As a co-organizer of SCA, the RIKEN Center for Computational Science (R-CCS) is actively promoting SCA/HPCAsia 2026, to be held in Osaka, Japan, in January 2026.

It will be held alongside the International Conference on High Performance Computing in Asia-Pacific Region (HPC Asia), a conference series focused on fostering idea exchange regarding HPC technologies.

SCA/HPCAsia 2026 will be held at Osaka International Convention Center from January 26 to 29, 2026. The theme: Everything with HPC—AI, Cloud, QC and Future Society.

For more information, please visit the SCA/HPCAsia 2026 website:

www.sca-hpcasia2026.jp

R-CCS Director Satoshi Matsuoka (left) discussing SCA/HPCAsia 2026.

Scientists were able to attended back-to-back symposia organized by the RIKEN Center for Biosystems Dynamics Research on re-engineering life cycles and organoids.

Two international symposia look at life cycles and organoid science

In March, 2025, the RIKEN Center for Biosystems Dynamics Research (BDR) held two back-to-back international symposia in Kobe, Japan, spotlighting groundbreaking advances in life sciences and regenerative medicine.

The first, the RIKEN BDR Symposium 2025, was themed 'Towards Redesigning Lifecycles'. The symposium focused on biological processes across an organism's entire life cycle—from fertilization and development to maturation and aging. A key goal of life sciences research is to translate comprehensive understanding of these systems into strategies that combat disease, extend healthy life spans and improve quality of life.

To achieve this, researchers must combine reductionist approaches, which break systems into their parts, with methods that piece them back together. The symposium served as a forum for world-leading interdisciplinary scientists who are pioneering novel technologies and concepts to reshape how we understand and potentially re-engineer biologically based life cycles. The event fostered active discussion and collaboration across diverse fields at the intersection of biology, engineering and computational science.

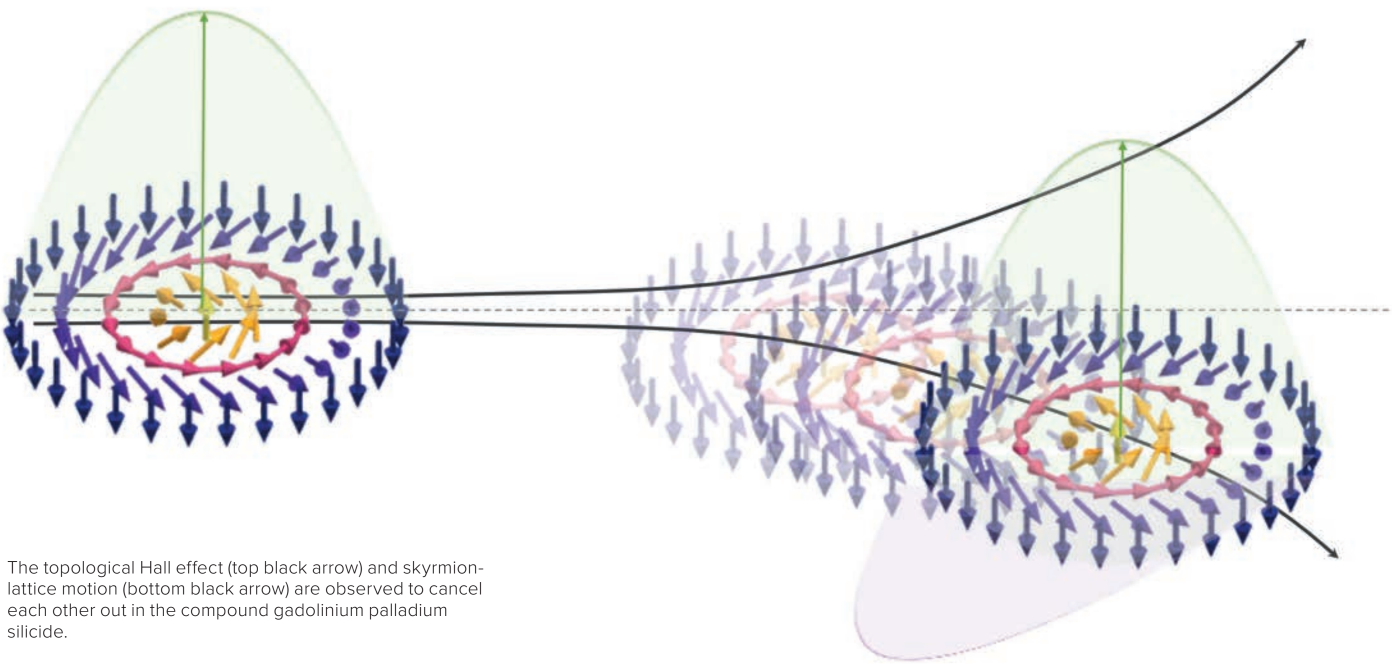
Immediately following the BDR Symposium, the 2025 RIKEN BDR–CuSTOM Joint Organoid Symposium, titled 'Integrated Organoid Science: Stem Cells, Engineering, Medicine', was held at the same venue. BDR and CuSTOM (the Center for Stem Cell & Organoid Medicine, Cincinnati Children's Hospital), USA—a leading center in organoid research—have had a memorandum of understanding on research collaborations since 2019.

Organoids are three-dimensional multicellular systems that mimic the structure and function of real organs and are generated through the self-organization of stem cells. This self-organization reflects the innate ability of stem cells to create complex tissue architectures by orchestrating the correct number and spatial arrangement of differentiated cells.

The second symposium brought together experts in stem-cell biology, biomedical engineering, chemistry and information science to explore the latest innovations in organoid research. Topics included human developmental biology, cancer modeling, organ-on-chip technologies and drug discovery. In addition to sharing new findings, participants also discussed ethical and societal considerations, as well as future challenges for the field.

These two high-level symposia reflect RIKEN BDR's commitment to advancing interdisciplinary research and contributing to transformative breakthroughs in life sciences, medicine and biotechnology.

https://www2.bdr.riken.jp/sympo/2025/
https://www2.bdr.riken.jp/joint-organoid/2025/



The topological Hall effect (top black arrow) and skyrmion-lattice motion (bottom black arrow) are observed to cancel each other out in the compound gadolinium palladium silicide.

SKYRMIONS

Magnetic whirlpools in motion

A new way of thinking about how swirling magnetic textures and mobile electrons interact could lead to compact, efficient and robust electronic devices

The future storage and processing of data stand to benefit greatly from tiny magnetic whirlpools known as skyrmions, which are robust against noise and may be useful in lower power consumption devices. The development of skyrmion-based technologies has received a boost from a simple and intuitive model for visualizing the complex motions of skyrmions developed by RIKEN researchers[1].

In addition to having mass and electric charge, electrons also possess spin—a form of intrinsic angular momentum.

In some crystalline materials, nearby electrons orient their spins relative to each other to form strange patterns. A skyrmion is one such example where the spin at the center points directly upward, while the surrounding spins gradually twist and point downwards to create a magnetic vortex.

As an electron moves through a lattice of skyrmions, its path bends due to the net (or 'emergent') magnetic field created by the skyrmions—a phenomenon known as the topological Hall effect. But this flow of electrons also causes the skyrmion lattice to move, resulting in an emergent electric field.

Given this complicated interplay, Max Birch and his colleagues at the RIKEN Center for Emergent Matter Science wanted to investigate what happens to the topological Hall effect when a skyrmion lattice moves.

The team chose the compound gadolinium palladium silicide (Gd_2PdSi_3) because its topological Hall effect is almost 100 times larger than those of similar materials. Their samples were also relatively small, making it easier to reach the high currents required to track skyrmion motion over micrometer length scales.

The researchers discovered that the skyrmion lattice motion totally canceled out the topological Hall effect (see image).

"It turns out that the topological Hall effect essentially scales with the velocity of the electrons relative to the skyrmions," explains Birch. "Once the skyrmions reach the same velocity as the electrons, the topological Hall effect will vanish, since it is totally canceled out by the induced emergent electric field."

An intuitive way of looking at this is that when the electrons and the skyrmions are moving at the same speed, their relative velocity is zero, and so there is no topological Hall effect.

Ironically, this demonstration on skyrmions, which are promising for forming the basis of future devices, means that they can be described by equations developed more than a century and a half ago. "We've shown that the topological effects can be expressed analogously to Maxwell's equations of electromagnetism," explains Birch.

This way of looking at skyrmion dynamics will be crucial for developing spintronic devices, the researchers believe. ●

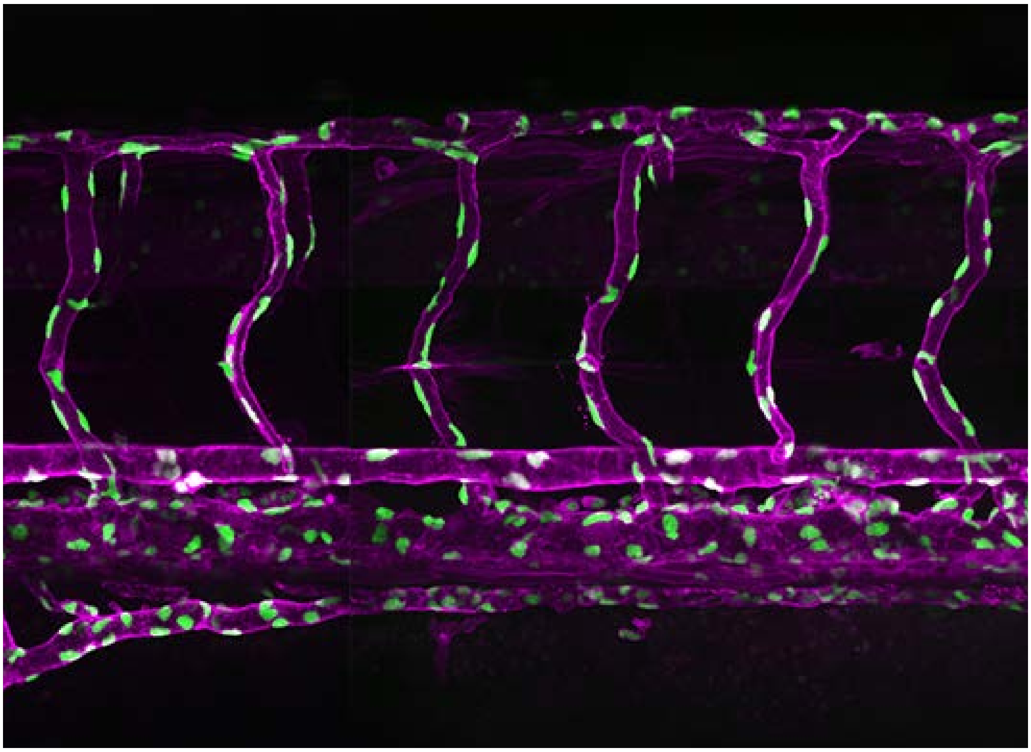
Reference

1. Birch, M. T., Belopolski, I., Fujishiro, Y., Kawamura, M., Kikkawa, A., Taguchi, Y., Hirschberger, M., Nagaosa, N. & Tokura, Y. Dynamic transition and Galilean relativity of current-driven skyrmions. *Nature* **633,** 554–559 (2024).

ANGIOGENESIS

Water gives cells a push in blood vessel formation

The flow of water helps drive the formation of new blood vessels in zebrafish



A confocal light micrograph showing blood vessels in a three-day-old zebrafish (magenta: endothelial cells of blood vessels; green: endothelial cell nuclei). RIKEN researchers have shown that water flow plays a role in the development of new blood vessels in zebrafish.

Water flow plays a surprising role in the formation of new blood vessels as zebrafish develop, RIKEN researchers have discovered[1]. This finding advances our understanding of how blood vessels sprout new branches through cell migration.

Blood vessels supply the cells in our bodies with the oxygen and nutrients they need to function and grow. Especially during development, blood vessels sprout new branches to supply blood to new areas. Tumors hijack this process to syphon off resources to support their proliferation.

New branches form through special cells at the leading edges of blood vessels—endothelial tip cells—migrating to new locations, where they form vascular sprouts. Efficient cell migration is driven by a process known as actin polymerization in which the building blocks of the polymer actin join together to form filaments.

Now, a team led by Li-Kun Phng of the RIKEN Center for Biosystems Dynamics Research has discovered another mechanism is also at work—they showed that water flow also assists endothelial tip cells to migrate in zebrafish.

"The fact that water flow and the build-up of hydrostatic pressure help endothelial tip cells to migrate is an exciting find," says Phng. "Most vascular biologists thought that actin polymerization is the only driving force for cell migration, but we've now shown that another process is also at play."

The team knew there had to be another process, because endothelial tip cells still migrated when they turned off actin polymerization in zebrafish in an earlier study.

In the present study, they showed that water flow is the second mechanism by generating zebrafish lacking genes that code aquaporins—channels that facilitate the movement of water in to and out of cells. When they did this, they observed defective migration of endothelial cells in the zebrafish.

"We found that when there are no aquaporins, meaning there's no water flow into endothelial cells, there is defective endothelial tip cell migration," says Phng. "And when we inhibited actin polymerization in aquaporin mutants, there was greater inhibition of endothelial tip cell migration. Combining these two results therefore shows that there are two mechanisms for endothelial tip cell migration during development in zebrafish."

"How endothelial cells migrate is very important because new blood vessels won't form if they fail to migrate," adds Phng. "Or if they migrate in a perturbed manner, mispatterned blood vessels can form, which can lead to problems with blood flow and poor perfusion of tissues."

The existence of two mechanisms means there is a backup if something goes wrong. "If one mechanism fails, the other mechanism will still be running to ensure that blood vessels form," notes Phng. ●

Reference

1. Kondrychyn, I., He, L., Wint, H., Betsholtz, C. & Phng, L.-K. Combined forces of hydrostatic pressure and actin polymerization drive endothelial tip cell migration and sprouting angiogenesis. *eLife* **13,** RP98612 (2025).

An illustration of rod-shaped *Bacteroides* bacteria. RIKEN researchers have found that, in combination with acetate, *Bacteroides* bacteria cause more fermentation of carbohydrates in the gut, which can reduce obesity.

GUT MICROBIOTA

A great combo for losing weight: gut bacteria and acetate

Researchers have found out how acetate reduces obesity in mice via gut bacteria

Supplying mice that have certain gut bacteria with extra acetate reduced their fat and liver mass, RIKEN researchers have found[1]. This discovery could lead to a new way to reduce obesity.

Obesity is a global epidemic, affecting more than 600 million people in the world. "Developing a treatment or prevention strategy for obesity is an urgent issue that must be solved quickly," notes Hiroshi Ohno of the RIKEN Center for Integrative Medical Sciences.

Obesity boosts the risk of developing heart disease, type-2 diabetes and cancer. In contrast, eating fiber lessens the risk of developing these diseases—even though mammals cannot directly digest fiber.

Bacteria in the large intestine ferment fiber and the byproducts are released into the gut lumen. The most common of these byproducts, acetate, has beneficial effects on host metabolism.

Dietary fiber is thus a good prebiotic, but its efficacy is limited by individual variation in the production of acetate and other useful byproducts.

To solve this problem, a team led by Ohno previously developed an acetate supplement called AceCel by combining acetate with cellulose. AceCel ensures acetate reaches the distal large intestine, where it can work its magic.

The team has now investigated how AceCel affects mouse metabolism and the composition of gut bacteria.

When given AceCel, both normal and obese mice lost weight without losing muscle mass. The mice didn't lose weight when fed other short-chain fatty-acid byproducts, indicating that acetate is the key.

To figure out how this was happening, the team performed further tests. While resting, AceCel-fed mice generated more energy from burning liver fat and less from burning carbohydrates than mice fed a normal diet. This promoted weight loss, resembling what happens during fasting.

By analyzing the gut microbiota, Ohno's team found that eating AceCel caused mice to have more *Bacteroides* bacteria in their guts. They showed that mice lost weight only when they both ate acetate and had *Bacteroides* bacteria in their intestines.

The team found that the combination of acetate and *Bacteroides* bacteria led to more fermentation of carbohydrates in the gut, resulting in less sugar for the host to process. This promotes fat-derived energy, and less sugar is stored as glycogen in the liver, reducing obesity.

"We found that acetylated cellulose can prevent obesity by modulating the function of the gut microbiome," says Ohno.

"Our next step is to confirm the safety and efficacy of using acetylated cellulose to treat obesity in humans," says Ohno. "If so, it could become an important ingredient in functional foods that prevent obesity."

Reference

1. Takeuchi, T., Miyauchi, E., Nakanishi, Y., Ito, Y., Kato, T., Yaguchi, K., Kawasumi, M., Tachibana, N., Ito, A., Shimamoto, S. *et al.* Acetylated cellulose suppresses body mass gain through gut commensals consuming host-accessible carbohydrates. *Cell Metabolism* advanced online publication May 2025. doi: 10.1016/j.cmet.2025.04.013

INFANT MICROBIOME

The link between food allergies and infant gut bacteria

The development of food allergies later in life is related in part to the type of bacteria present in the guts of one-month olds

Certain gut bacteria in one-month-old infants are linked to sensitizations to food antigens and allergies, whereas others are not, RIKEN researchers have found[1]. This suggests that some probiotics might be useful for defending against food allergies.

Food allergies arise when the body mistakenly identifies a protein in a food as a threat. It mounts an immune response to the protein by producing an antibody called immunoglobulin E, which has several varieties depending on the trouble-making food protein.

"We hope that a better understanding of neonatal gut microbiota will help generate ideas for allergy-prevention strategies."

Bacteria in the gut soon after birth aid the normal development of the immune system and protect against some diseases. However, research into the link between gut microbiota and allergies has produced mixed results.

The RIKEN team analyzed gut bacteria in two groups of Japanese children: 270 children from families with histories of allergies and 245 children from a previous study designed to test allergy treatments.

The researchers looked at levels of immunoglobulin E specific to milk, peanuts, egg white and wheat in the blood from one year after birth to seven years old. They also collected gut microbiota data, starting from one week after birth. By analyzing both, the team hoped to find gut microbiota biomarkers for food sensitization and allergies.

Of all the time points over the seven years, gut microbiota present one month after birth showed the most significant connection to food-specific immunoglobulin E levels in the blood, even when the children were seven years old.

"The early neonatal period is critical for immune system development," says Hiroshi Ohno at the RIKEN Center for Integrative Medical Sciences. "Our results emphasize this, showing that the type of bacteria in the gut at this critical time is the best at predicting immune responses to food seven years down the road."

Babies with *Bifidobacterium*-dominant microbiomes were significantly less likely to develop food sensitization to egg whites than babies with microbiomes dominated by one of the other categories of bacteria, the team found. This was also the trend for allergic reactions to egg whites later in life.

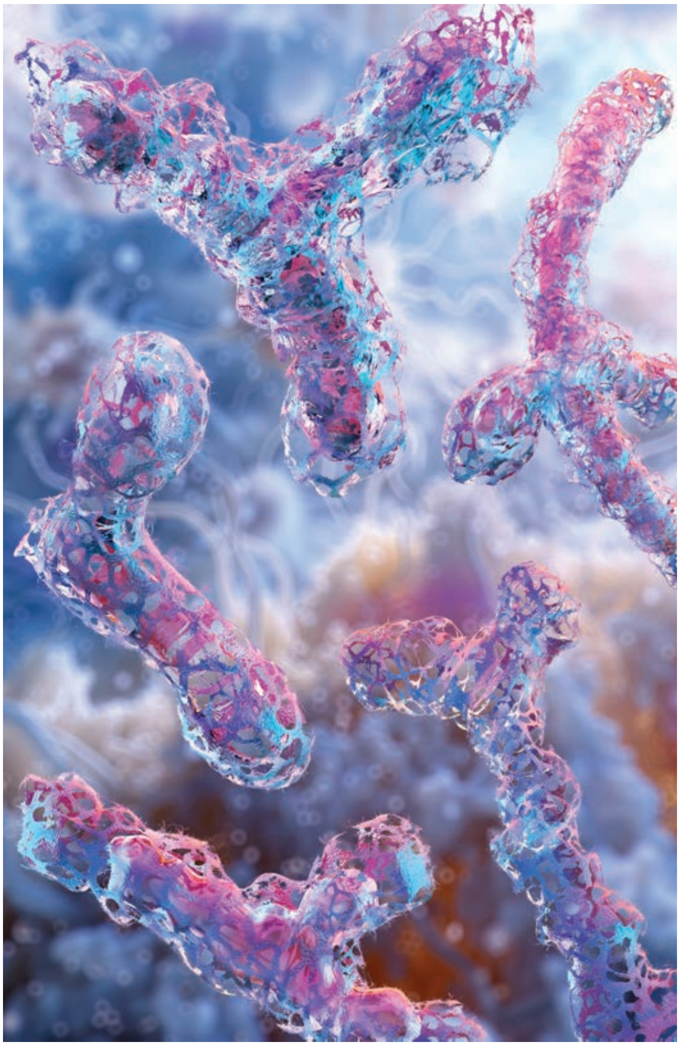


Illustration of *Bifidobacterium* bacteria. Using *Bifidobacterium* as a probiotic during infancy might help prevent children developing food allergies, RIKEN researchers have found.

By analyzing other data for the 515 children, the team found that the gut microbiota was linked to the type of delivery and the amount of breast feeding. Infants who were delivered normally and received less breast feeding were best off, having *Bifidobacterium*-dominant microbiomes.

"We hope that a better understanding of neonatal gut microbiota will help generate ideas for allergy-prevention strategies," says Ohno. "We found that the intervention with *Bifidobacterium* during infancy might help prevent later food allergies, especially in infants who are the most at risk." ●

Reference

1. Shibata, R., Nakanishi, Y., Suda, W., Nakano, T., Sato, N., Inaba, Y., Kawasaki, Y., Hattori, M., Shimojo, N. & Ohno, H. Neonatal gut microbiota and risk of developing food sensitization and allergy. *The Journal of Allergy and Clinical Immunology* **155,** 932–946 (2025).

QUANTUM BATTERIES

Overcoming hurdles to realizing quantum batteries

A proposal for a new type of quantum battery overcomes long-standing problems with their realization

A theoretical analysis by RIKEN researchers demonstrates an innovative design for a new type of quantum battery[1]. Such a battery could find use in quantum communication and computing.

Quantum batteries that harness quantum phenomena such as superposition, entanglement and coherence could greatly enhance the storage and transfer of energy. Compared to their classical counterparts, quantum batteries potentially offer improved charging power, greater energy storage, and superior work extraction efficiency.

Various proposals for quantum batteries have been proposed, but their practical realization has remained elusive.

Energy loss and decoherence constitute critical limitations to the performance of quantum batteries in practical scenarios involving remote charging and energy dissipation. These are common issues for quantum devices as they cause a quantum system to lose its key properties, such as entanglement and superposition, resulting in low practical performance.

Quantum batteries based on light-based systems that channel photons in non-topological waveguides (for example, optical nanofibers) have been proposed. The energy-storage efficiency of these quantum batteries is significantly degraded by the dispersion of photons within the waveguide. In addition, environmental dissipation, noise and disorder can degrade battery performance.

In a recent theoretical study, researchers from the RIKEN Center for Quantum Computing (RQC) and Huazhong University of Science and Technology in China have addressed two long-standing challenges that have hindered the practical realization of quantum batteries.

A conceptual image of a futuristic battery. RIKEN researchers have theoretically proposed a new type of quantum battery.

Specifically, the joint research team demonstrated the feasibility of quantum batteries that achieve perfect long-distance charging and immunity to dissipation by harnessing unique topological features.

Surprisingly, the international team found that dissipation—typically regarded as detrimental to battery performance—can be harnessed to transiently boost the charging power of quantum batteries.

The team demonstrated several key advantages that could make topological quantum batteries feasible for practical applications. In particular, they found that it is possible to achieve near-perfect energy transfer by leveraging the topological properties of photonic waveguides.

"Our research provides new insights from a topological perspective and gives us hints toward the realization of high-performance micro-energy storage devices," says first author, Zhi-Guang Lu. "By overcoming the practical performance limitations of quantum batteries caused by long-distance energy transmission and dissipation, we hope to accelerate the transition from theory to practical application of quantum batteries."

"Looking ahead, we will continue working to bridge the gap between theoretical study and the practical deployment of quantum devices—ushering in the quantum era we have long envisioned," adds Cheng Shang of RQC. ●

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PERCEPTUAL MEMORY

How sleep reinforces memories linked with emotional experiences

Neuroscientists have discovered how memories tied with emotional events are strengthened in mice during sleep

Perceptual memories are reinforced during sleep. RIKEN researchers have now found that non-REM sleep is the critical sleep stage for this strengthening in mice.

How the mouse brain strengthens memories linked to experiences of positive emotions such as joy or happiness during sleep has been uncovered by RIKEN researchers[1]. The findings could help scientists understand the neurological basis for overcoming conditions such as addictions.

Events that generate strong emotions, whether positive or negative, create strong and enduring memories of accompanying sensory information such as music, smells and textures. These memories are known as perceptual memories.

Sleep is essential for consolidating memories. But it is unclear whether rapid eye movement (REM) sleep—the sleep stage when we dream vividly—or non-REM sleep is more important for solidifying memories of emotional events.

Now, a team led by Masanori Murayama of the RIKEN Center for Brain Science has found that non-REM sleep is the key sleep stage for strengthening perceptual memories in mice.

"Traditionally, REM sleep has been thought to be the primary stage for emotional memory processing," says Murayama. "Our findings challenge this idea and instead support non-REM sleep as the critical stage."

The team also found that the amygdala, the brain's emotional center, plays a key role in this process.

"This is the first study to demonstrate perceptual memory enhancement through emotions in experimental animals," explains Murayama. "We identified the critical neural circuitry involved in perceptual memory enhancement."

To investigate what the brain does differently during sleep when emotions are involved, Murayama's team established mouse equivalents of neutral and emotional events.

On day 1 of the experiment—the learning period for a neutral situation—male mice were allowed to explore a smooth texture. The next day—the testing period—they could explore both grooved and smooth textures. Although they still retained the memory of the smooth texture on day 2, they preferred to explore the grooved texture, because mice innately like novel environments.

However, when the smooth texture was paired with a positive emotional experience—interaction with a female mouse—the memory of the texture lasted much longer. Even after four days, the mice still preferred the smooth texture. This showed that the experimental setup could produce emotionally enhanced texture memories in mice.

The findings point to potential treatments for conditions such as addiction, in which symptoms are sometimes triggered by perceptual information in a phenomenon called flashback. The team will explore how these findings apply to addiction and other disease models, such as age-related memory decline.

"It will be important to examine whether we can recover or even strengthen memories in aged mice," says Murayama. "Our ultimate goal is to use this knowledge to develop treatments that improve mental health and memory-related conditions."

Reference

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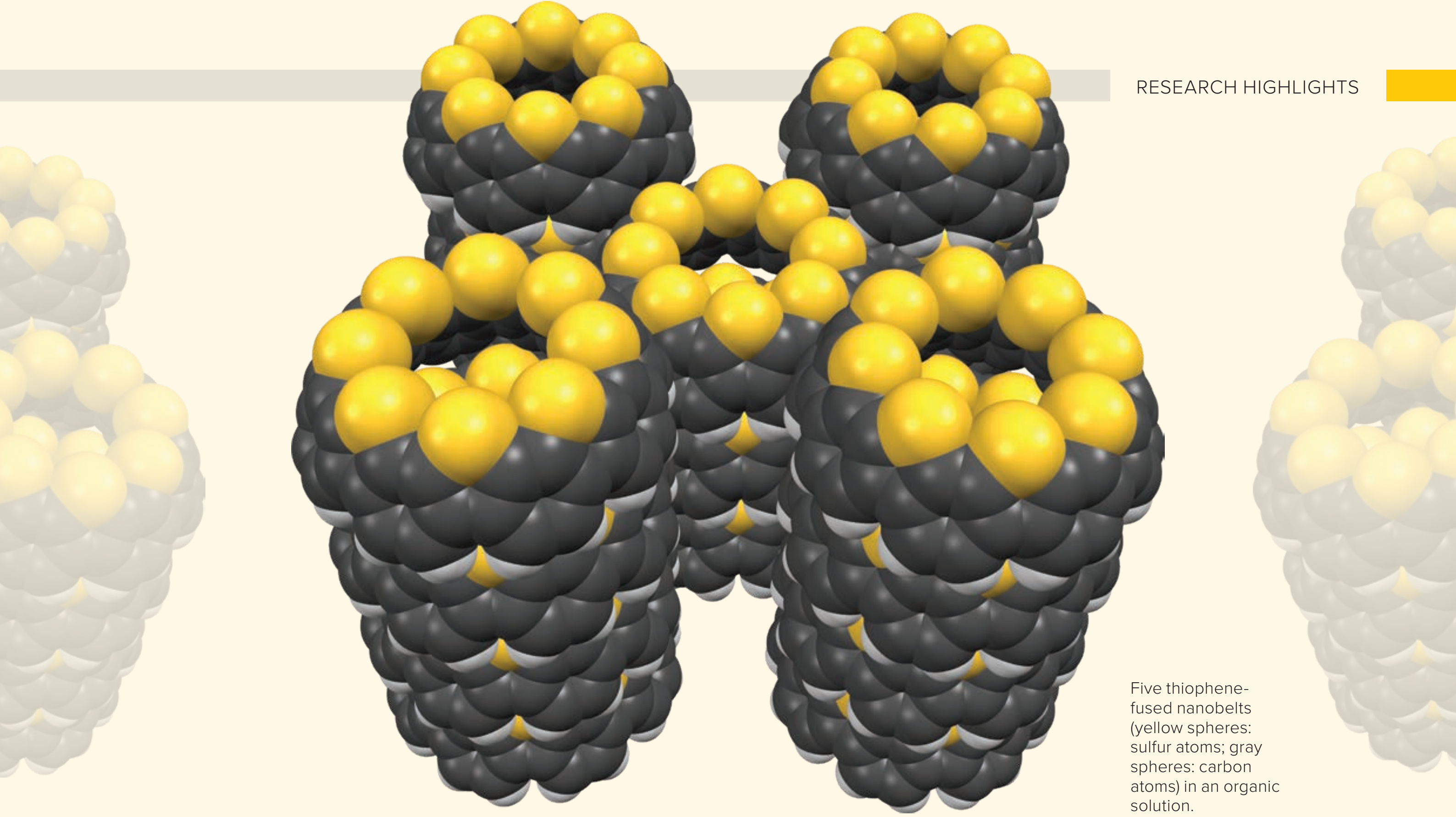

Five thiophene-fused nanobelts (yellow spheres: sulfur atoms; gray spheres: carbon atoms) in an organic solution.

CARBON NANOMATERIALS

Sulfur-capped carbon nanobelts promise novel applications

A remarkably easy way to cap carbon nanobelts with sulfur atoms has been demonstrated

RIKEN chemists have hit upon a fast and easy way to combine so-called nanobelts of carbon with sulfur-containing functional groups[1]. This new material has intriguing properties that make it promising for use in novel optoelectronic devices.

Ever since their discovery in 1991, carbon nanotubes—tiny hollow cylinders made entirely from carbon atoms—have been attracting a lot of interest, being used in applications ranging from electronics to medicine.

Carbon nanobelts are cross-sectional slices of carbon nanotubes. They could be used in electronic and optoelectronic devices and as building blocks for carbon nanotubes. Despite attempts starting as far back as the 1950s, they weren't synthesized until 2017 by a team led by Kenichiro Itami, now of the RIKEN Molecule Creation Laboratory.

That achievement has sparked a flurry of activity to create similar nanobelts. "People realized that it's not a dream molecule, that it is possible to synthesize it," says Itami. "Therefore, many research groups in the world are now making a lot of different kinds of nanobelts after our demonstration."

Itami and his team have also been attempting to make new molecules based on carbon nanobelts. Now, they have combined carbon nanobelts with thiophene (see image)—a ring-shaped compound made up of one sulfur atom and four carbon atoms.

The motivation for combining thiophene and carbon nanobelts is that thiophene is a function-rich material with interesting semiconducting and fluorescence properties.

The new molecule turned out to be surprisingly easy to make. "It's amazingly simple," says Itami. "It's just a single-shot reaction."

Even Itami was taken aback by how easy it was. "Hiroki Shudo, the first author of this paper, proposed the idea to me after reading a paper, saying, 'I think we can do this'", recalls Itami. "And then boom, it worked! That was a big surprise to me."

Another surprise was that all the nanobelts aligned with their sulfur sides up on a copper surface, but with their sulfur sides down on a gold surface. "That was really unexpected," notes Itami. "We're now seeking to understand why it happens."

The thiophene-fused nanobelts are more than just interesting chemistry curiosities though—they could find applications in optoelectronic devices and polar materials.

"Several research groups in other countries are extremely excited about using our molecule in devices and are looking to collaborate with us," says Itami. "So we're now sending the molecule to them to initiate international collaborations."

The same synthesis strategy used to make the thiophene-fused nanobelts could also be used to create other varieties of carbon nanobelts. Itami and his team are currently seeing what other molecules they can make with it.

Reference

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Girolline, a compound extracted from a certain species of sea sponge, possesses possible medicinal properties. RIKEN researchers have found the mechanism behind these properties.

BIOACTIVE COMPOUNDS

How a sea-sponge compound may fight cancer and malaria

The origin of possible medicinal properties of a compound from a sea sponge has been discovered

RIKEN researchers have discovered how a compound from a sea sponge exerts possible antitumor and antimalarial effects[1]. Their findings suggest that it could also be useful for research in areas such as aging and mitochondrial health.

Sea sponges are important sources of biological compounds, since they use chemical means to protect themselves. Girolline is one of several compounds with biological functions that have been isolated from the sea sponge *Pseudaxinyssa cantharella*.

Girolline may possess antitumor properties. This was thought to be due to it preventing ribosomes—the cell's protein production factories—from translating messenger RNA into the amino-acid sequence of proteins. However, its effects and their underlying mechanisms remained relatively unexplored.

Now, RIKEN scientists have gained a greater understanding of how girolline exerts its biomedical effects.

"We were able to discover that girolline acts by a new mechanism of action," says Tilman Schneider-Poetsch of the RIKEN Center for Sustainable Resource Science. "It works selectively on certain amino-acid sequences, rather than as a general inhibitor of translation from RNA to proteins."

The team found that girolline acts by modulating the activity of eIF5A, a translation elongation factor that helps the ribosome navigate difficult-to-translate stretches of amino-acid sequences. When the speed of the ribosome slows, eIF5A binds and enhances the rate of amino-acid incorporation, preventing the ribosomes from stalling.

Girolline prevents eIF5A from binding to the ribosome. Without the aid of eIF5A, the ribosome will get stuck on certain sequence stretches. The stalled ribosomes are then attacked by the ribosome-associated quality control pathway, which degrades the protein that is under production. This premature degradation of unfinished proteins appears to partially account for girolline's toxicity.

The sequences that cause stalling include those coding the amino acids proline and lysine, especially when lysine is encoded by the RNA sequence AAA (three adenine bases in a row).

This finding may have implications for girolline's antimalarial effect, because messenger RNA molecules of the parasite that causes malaria tend to have stretches with many adenine bases, making them sensitive to the effects of girolline.

eIF5A helps to maintain the function of mitochondria, and its dysfunction has been implicated in the aging process. Girolline is thus expected to be a useful chemical tool for dissecting eIF5A's function in mitochondrial maintenance and aging.

"Girolline, because of its selectivity, is a new tool that we will be able to use to investigate the role of eIF5A, an important protein involved in aging, neurodegeneration and cancer," says Schneider-Poetsch. "We're currently carrying out follow-up projects to investigate this." ●

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SUPERCONDUCTIVITY

An easy way to control superconductivity

Superconductivity in layered materials can be tuned by a small angular twist

A straightforward way to control superconductivity that involves merely twisting atomically thin layers within a layered device has been demonstrated by physicists at RIKEN[1]. This advance could help to realize more energy-efficient technologies and quantum computing.

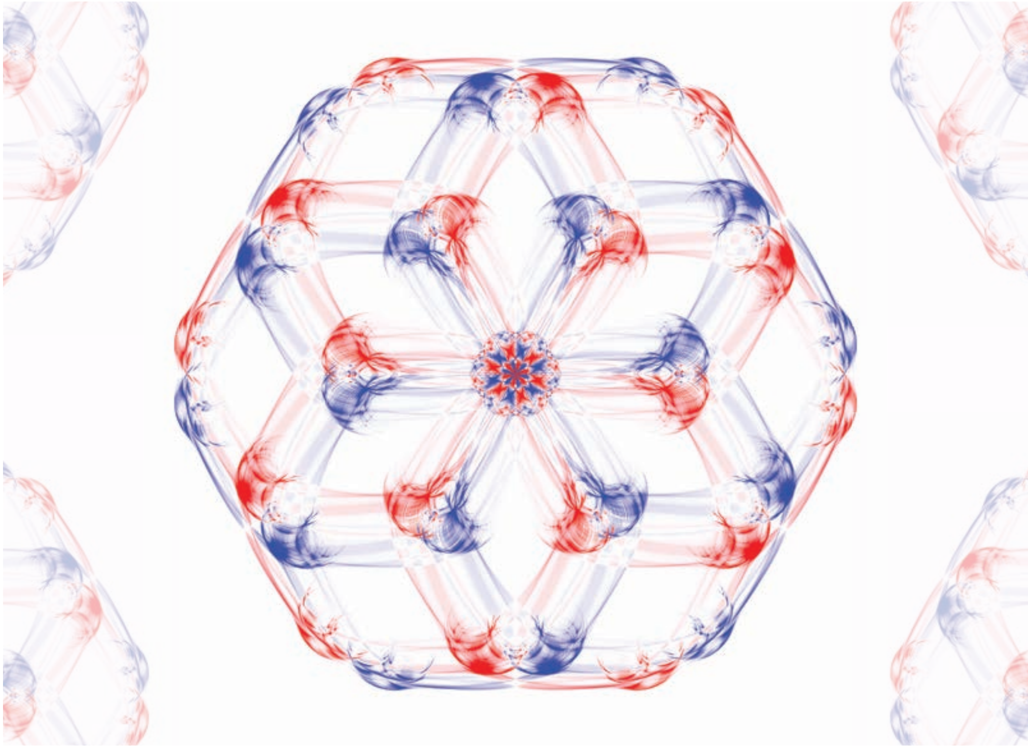
When cooled to low temperatures, superconductors conduct electricity without any resistance. That's because their conduction electrons pair up and form so-called Cooper pairs.

An important parameter for superconductors is the superconducting gap, which is the energy needed to break Cooper pairs apart. The larger the superconducting gap, the higher the critical temperature for superconductivity. Tuning the superconducting gap is also important for optimizing the nanoscale behavior of Cooper pairs, which can enhance the functionality of quantum devices.

To date, efforts to control the superconducting gap have largely focused on the physical position of particles in 'real space'. For example, the superconducting gap can be modified by adding defects or interfaces to the superconducting material.

However, achieving control in momentum space—a different mapping based on the energy state of the system—has remained elusive. Fine-tuning the gap in momentum space is crucial for the next generation of superconductors and quantum devices.

Now, a team led by Tetsuo Hanaguri of the RIKEN Center for Emergent Matter Science (CEMS) has succeeded in finely tuning the superconducting gap in momentum space. They did this by adjusting the twist angle between an ultrathin layer of niobium diselenide, a well-known superconductor and the underlying graphene surface.



A simulation of the interference that occurs between quasiparticles in graphene and ultrathin niobium diselenide layers that are twisted by 24 degrees with respect to each other. The simulation agrees well with experimental measurements.

Using advanced imaging and fabrication techniques, Hanaguri and his team precisely adjusted the twist angle of the layers. This modification produced measurable changes in the superconducting gap within momentum space, unlocking a novel 'knob' for precisely tuning superconducting properties.

"Our findings demonstrate that twisting provides a precise control mechanism for superconductivity by selectively suppressing the superconducting gap in targeted momentum regions," explains Masahiro Naritsuka, also of CEMS.

"In the short term, our research deepens the understanding of superconducting systems and inter-layer interactions, advancing the design of superconductors with tailored properties," says Hanaguri. "In the long term, it lays the foundation for developing energy-efficient technologies, quantum computing, and beyond."

The team is now exploring whether it is possible to tune both spin and momentum at the same time. "Next steps involve investigating whether magnetic layers can be integrated into the structure to enable both spin and momentum selectivity," says Hanaguri. "These advances could unlock new research opportunities and pave the way for developing innovative materials and devices." ●

Reference

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BRAIN VASCULATURE

Monkey brain map reveals the importance of sight

Blood vessels in the macaque brain are densest in energy-intensive regions such as the visual cortex

In the brain, not all blood flow is created equal. RIKEN researchers have developed a detailed cortical layer map of the blood vessels that weave through the brain of macaque monkeys. It reveals how blood supply is finely tuned to fuel critical functions such as perception and cognition[1].

The network of blood vessels in the brain supplies the various brain regions with oxygen and nutrients. Determining the relationship between the brain's vascular network and its energy demands is important for understanding how the brain's inner workings might create vulnerabilities to stroke, Alzheimer's disease and other neurological diseases.

"This could provide a framework for understanding differences in brain function and energy needs across species."

However, there is still much we don't understand about the architecture of the vascular network in the brain.

Now, Joonas Autio of the RIKEN Center for Biosystems Dynamics Research and co-workers have mapped blood volume across cortical layers and the entire cortex of macaque monkeys by using high-resolution magnetic resonance imaging.

Their measurements revealed that the distribution of blood vessels is far from uniform, and that these variations align with neuroanatomical differences. The vasculature scales positively with neuron density, whereas layers and regions with higher synaptic densities exhibit relatively sparser vascularization.

In particular, blood vessels are concentrated in regions essential for sensory processing, particularly vision. In contrast, they are sparser in areas responsible for higher cognitive functions, such as abstract thinking and decision making.

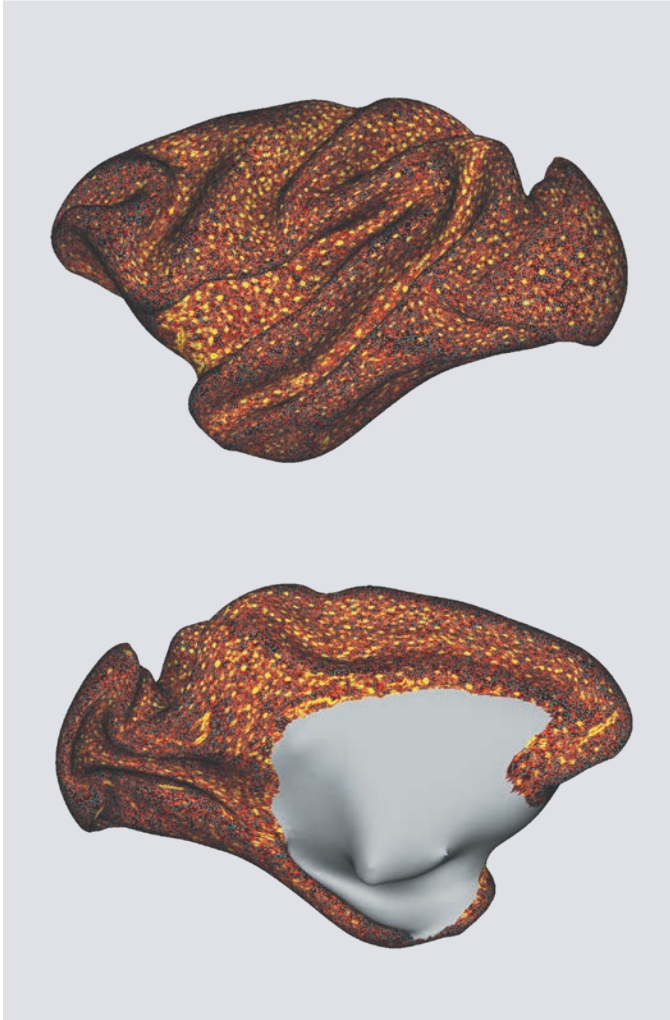
This uneven distribution in the macaque brain probably reflects the prioritizing of more pressing, survival-driven tasks managed by the visual cortex and other regions processing external stimuli over more cognitive functions.

"Evolutionary pressures may have optimized the vascular architecture to support the high metabolic demands of visual processing," says Autio. "This was likely driven by the need for efficient foraging and competition in visually dominant environments."

These methodological developments could have clinical implications. A better understanding of how blood flow is distributed across different brain regions and layers could help unravel how vascular dysfunction impacts disorders linked to neurodegeneration and aging. The ability to map feeding arteries and draining veins with such precision also offers hope for developing targeted therapies for neurological conditions, Autio says.

The findings raise intriguing questions about human brains. While similar cortical layer vascular maps don't yet exist for people, Autio suspects that our brains might have denser vascular networks in regions associated with working memory and higher order functions, as humans tend to engage in more complex and sustained cognitive tasks than monkeys.

"This could provide a framework for understanding differences in brain function and energy needs across species," he says. ●



A high-resolution image showing the distribution of blood vessels in the macaque brain. Yellow circles indicate the sizes of vessels and cyan dots show the centers of vessels.

Reference

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PHOTOLUMINESCENCE

How carbon nanotubes give light an energy boost

Carbon nanotubes can emit light that has a greater energy than light shone on them—now researchers think they understand the mechanism behind this feat

Three RIKEN physicists have discovered how tiny tubes of carbon spit out light that is more energetic than the light shone on them[1]. This finding could help to exploit the process in applications such as solar power and biological imaging.

Some special paints glow when you shine ultraviolet light on them. They are classical examples of conventional photoluminescence: when illuminated by high-energy light (ultraviolet light), they emit lower energy light (visible light).

But surprisingly, certain materials exhibit the opposite effect—shine light on them and they emit higher energy light.

This curious phenomenon is called up-conversion photoluminescence (UCPL). It could boost the efficiency of solar cells, for example, by converting low-energy light into higher-energy wavelengths suitable for generating electricity.

In regular photoluminescence, light hits a material and kicks an electron into a higher energy level, leaving behind a positively charged 'hole'.

Initially, the electron–hole pair sticks together in a state known as an exciton. But eventually, the electron and hole recombine, emitting light in the process.

In normal photoluminescence, the exciton loses energy to the material, and hence the emitted light carries away less energy than the incoming light brought in. In UCPL, however, the exciton receives an energy boost from the material by interacting with vibrations in it known as phonons.

Now, Yuichiro Kato and two colleagues, all at the RIKEN Center for Advanced Photonics, have pinned down exactly how UCPL works in single-walled carbon nanotubes—hollow cylinders of carbon just a few billionths of a meter wide.

Previous theories had suggested that UCPL could only happen in single-walled carbon nanotubes if excitons were temporarily trapped by defects in the nanotube's structure. But the researchers found that UCPL occurred with high efficiency even in defect-free nanotubes, suggesting that an alternative mechanism was at work.

The trio discovered that when an electron is excited by light, it gets a simultaneous energy boost from a phonon to form a 'dark exciton' state. After losing a little energy, the exciton finally emits light with more energy than the incoming laser.

Raising the temperature produced a stronger UCPL effect, confirming predictions made by their model. "Phonons are more abundant at higher temperatures, enhancing the likelihood of phonon-mediated transitions," says Kato.

The researchers plan to study the possibility of cooling a nanotube using laser illumination to remove thermal energy by UCPL and explore energy-harvesting opportunities to create a nanotube-based device.

"By establishing an intrinsic model of UCPL in single-walled carbon nanotubes, we hope to open up new possibilities for designing advanced optoelectronic and photonic devices," says Kato.

Reference

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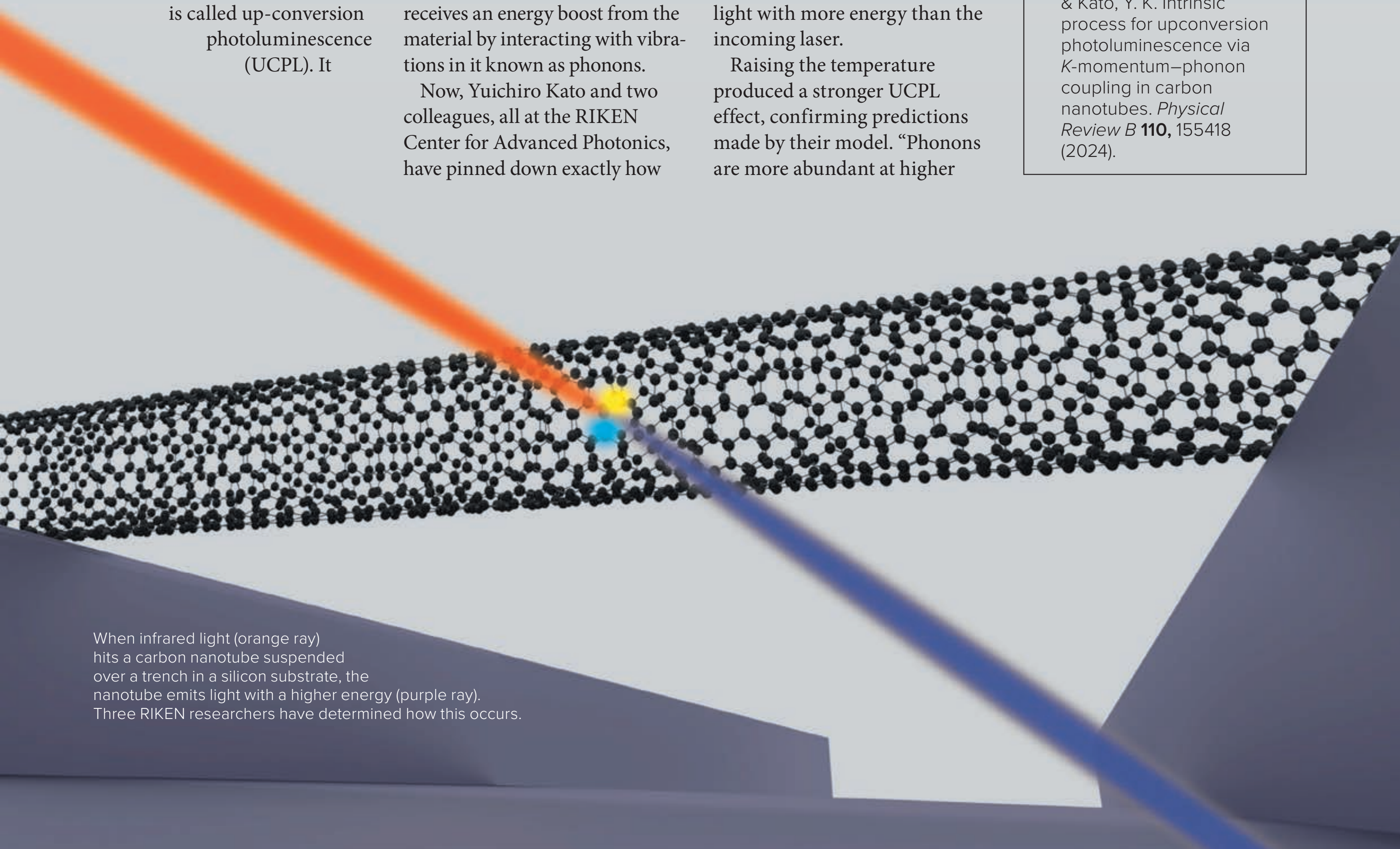

When infrared light (orange ray) hits a carbon nanotube suspended over a trench in a silicon substrate, the nanotube emits light with a higher energy (purple ray). Three RIKEN researchers have determined how this occurs.

EMOTIONAL INFERENCE

How the brain allows us to infer emotions

The brain region responsible for inferring emotions has been found for the first time

Two RIKEN neuroscientists have discovered the brain circuitry that allows rats to learn inferred emotions[1]. This could help to open up new ways for treating anxiety and trauma-related disorders.

A child often watches wasps fly in and out of a nest. If she is stung by a wasp for the first time, she might subsequently feel anxious on just seeing the wasp's nest—even if she wasn't near the nest when stung. The child's brain links the painful sting with the sight of the nest. This is an example of an inferred emotion.

To study the neural mechanisms behind inferred emotions, Xiaowei Gu and Joshua Johansen, both at the RIKEN Center for Brain Science, created a similar situation in rats.

Rats learned a neural association between a noise and an image. Later, they experienced unpleasantness while seeing the image—a process called aversive conditioning. The next day, the rats froze on hearing the noise, indicating that they too can learn inferred emotions.

Gu and Johansen found that a brain region called the medial prefrontal cortex (mPFC) is the basis of emotional inference.

"Decades of studying aversive learning in rodents has revealed that the amygdala is a critical site for storing simple emotional memories involving directly experienced associations," explains Johansen. "However, our new findings indicate that the mPFC is a central brain region for higher order human-like emotions, which involve internal models and inference."

Before aversive conditioning, mPFC neurons responded similarly to the image and noise, whether the stimuli had been paired or not. But after aversive learning, there were many more noise-responsive and noise/image co-responsive neurons—provided the noise and image had been initially paired when presented to the rats.

This occurred because the initial sensory pairing 'tagged' co-responsive neurons, priming them to activate during aversive conditioning.

Blocking the mPFC during the aversive learning stage prevented rats from being able to make the later inference. That's because the image and the unpleasant experience, and indirectly the noise, could not be properly linked in the rats' minds.

Blocking the output from the mPFC to the amygdala during testing also prevented rats from responding to the noise with fear. In this case, however, it was because they could not recall the inferred memory, even though the association had been made the day before. The rats still froze on seeing the image, indicating that only the higher-order ability of inference is rooted in the physical changes in mPFC neurons.

"Our study opens the door for researchers everywhere to examine the neural mechanisms that mediate higher order emotions, which are more relevant to human psychiatric conditions like anxiety or trauma-related disorders," adds Johansen. ●

Initially a source of curiosity, a wasp nest can stir up feelings of anxiety and fear in a child after they have been stung by a wasp—even if the sting occurred away from the nest. RIKEN researchers have found that such inferred emotions are generated in the medial prefrontal cortex of rats.

Reference

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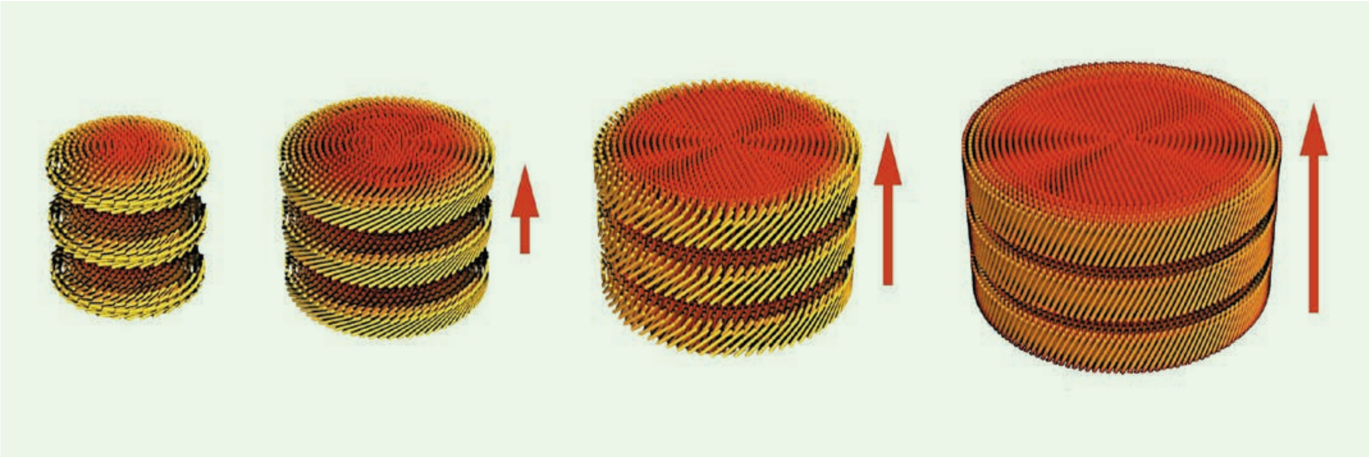

Increasing the size of the magnetic field (red vertical arrows) applied to rod-like viruses during self-assembly produces thicker, larger disks.

SELF-ASSEMBLY

Controlling self-assembly better than nature

Applying a magnetic field to rod-like viruses induces them to form disks of tunable shape and size

Seeking to mimic self-assembly processes that occur naturally, RIKEN researchers have demonstrated that the self-assembly of rod-shaped viruses can be controlled by applying a magnetic field[1]. This advance could help to develop artificial self-assembly processes that are more controllable than existing ones.

When constructing a house, a bricklayer has to take each brick and cement it in place. But in many biological processes, the 'bricks' arrange themselves into structures spontaneously.

Due to their high efficiency and precision, such self-assembly processes are used in nanotechnology and materials science.

Natural self-assembly processes usually terminate once the structure reaches a certain size. For example, the protein shell of a virus will stop growing when it attains a certain diameter. In contrast, artificial self-assembly processes tend to continue indefinitely.

"Because we can't control the structure size in artificial self-assembly processes, the final size and shape distribution of such structures is very broad," explains Yasuhiro Ishida of the RIKEN Center for Emergent Matter Science.

"How can nature control structure size in such highly uncontrollable systems?"

Ishida is keen to discover how nature controls the size in self-assembly processes and then try to replicate it in the lab.

"Our question is: how can nature control structure size in such highly uncontrollable systems?" says Ishida. "There must be some mechanism that automatically controls the size and shape even under equilibrium conditions."

Now, Ishida's team has used rod-shaped viruses to demonstrate a self-assembly system that produces disks whose diameters can be controlled by a magnetic field. The magnetically induced twisting exploits a property known as chirality that many natural systems use to limit structure size.

Being chiral, the viruses prefer to pack together with a slight twist between neighbors. When no magnetic field is applied, the disk accumulates a twist during self-assembling, which causes it to stop growing once it reaches a certain diameter (image, left).

Applying a magnetic field to the viruses during self-assembly reduces the amount of twisting between neighboring viruses, which allows the disk to grow larger. Varying the magnetic field intensity alters the disk size accordingly (see image).

"This process surpasses natural systems in that it can adaptively change the end point of its growth," says Ishida.

When the researchers turned off the magnetic field after the disks had formed, the disks began to slowly unravel, producing corkscrew-like structures.

"I was so surprised when my students showed me the video of this unravelling," recalls Ishida. "It was very beautiful to watch."

Ultimately, Ishida's team aims to go beyond nature and develop innovative self-assembly systems. "Our ultimate goal is to use self-assembly to perform things such as small-scale surgeries in the body, for example," says Ishida. ●

Reference

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COGNITIVE NEUROSCIENCE

Human brain wired for cooperation in large groups

Large groups can promote teamwork thanks to how the brain works

RIKEN neuroscientists have discovered that, contrary to conventional wisdom, cooperation can thrive in large groups[1]. Insights from the study could help to develop better strategies for promoting teamwork in organizations.

Humans are social creatures and rely on teamwork to succeed. This ability to collaborate is deeply rooted in how our brains function.

Traditionally, scientists thought that cooperation is harder in larger groups because it is more challenging to interact with everyone enough to build trust. Earlier studies reinforced this belief, suggesting that cooperation tends to diminish in larger groups.

Now, Rei Akaishi of the RIKEN Center for Brain Science and coworkers have demonstrated that larger groups can actually foster greater cooperation.

RIKEN researchers have uncovered some of the neuroscience behind how teams cooperate.

They conducted an experiment in which 83 people played the prisoner's dilemma game—a scenario in which players choose between cooperating for mutual benefit or acting selfishly. Groups consisted of two to six people, and participants were allowed to leave groups they found undesirable or remove uncooperative members.

The results were unexpected: people in larger groups cooperated more frequently.

Group size did not directly promote cooperative behavior; rather it influenced how people managed memory and made decisions during social interactions.

Even when participants struggled to clearly recall past interactions, they often defaulted to pro-social behaviors, relying on their general inclinations to trust or cooperate. This suggests that when memory becomes unclear, people prioritize cooperation over caution, enabling smoother group dynamics.

Throughout the game, participant brain activity was monitored using functional magnetic resonance imaging. Specific brain regions, such as the fusiform gyrus and precuneus, processed memories of past interactions, while the nucleus accumbens connected these memories to feelings of reward.

The prefrontal cortex played a critical role in weighing these memories against personal tendencies, guiding decisions about whether a participant should cooperate with someone who might have previously betrayed them. When memories were less reliable, the brain appeared to naturally encourage cooperation, perhaps as a way to maintain group harmony.

These findings offer a fresh perspective on how humans build trust and interact within groups. They highlight the benefits of flexible and fluid social connections for fostering cooperation—allowing people to freely form and adjust connections, rather than adhering to rigid group structures—which could lead to better collaboration.

This insight is particularly relevant in today's world, where digital platforms and online communities thrive on dynamic, ever-evolving relationships.

"Our work aims to provide practical strategies for creating more harmonious and productive communities," says Akaishi. "Our findings could help improve teamwork in schools, workplaces, and online environments."

"We plan to further explore our findings in these real-world settings to better understand how factors like culture, leadership, and individual personalities influence group behavior," adds Akaishi. ●

Reference

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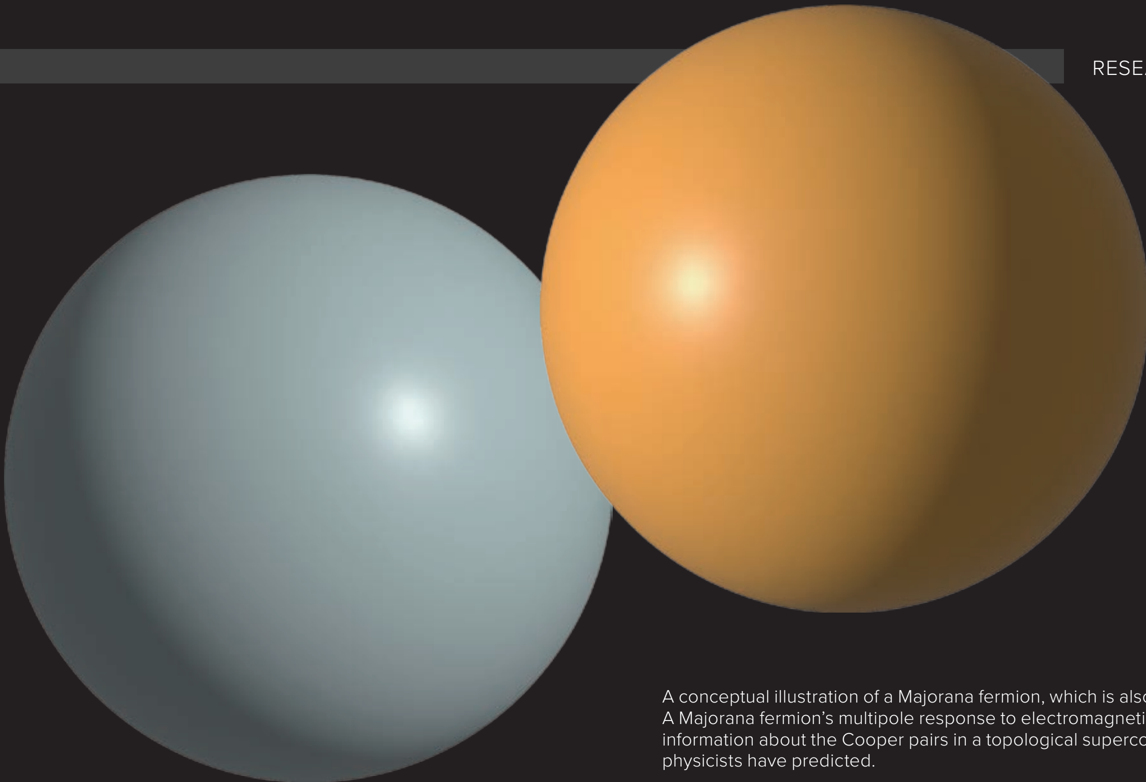

A conceptual illustration of a Majorana fermion, which is also its own antiparticle. A Majorana fermion's multipole response to electromagnetic waves provides information about the Cooper pairs in a topological superconductor, two RIKEN physicists have predicted.

TOPOLOGICAL SUPERCONDUCTORS

Revealing the hidden symmetries of a superconductor

A superconducting surface's electromagnetic response can reveal the secrets of the exotic particles beneath

A possible method for probing the properties of exotic particles that exist on the surfaces of an unusual type of superconductor has been theoretically proposed by two RIKEN physicists[1].

When cooled to very low temperatures, two or more electrons in some solids start to behave as if they were a single particle.

This can give the material some exotic properties. For example, superconductivity arises in some materials because electrons form into couples known as Cooper pairs that move through the material without facing any electrical resistance.

Now, Yuki Yamazaki from the RIKEN Condensed Matter Theory Laboratory and Shingo Kobayashi from the RIKEN Center for Emergent Matter Science have theoretically proposed a method that could provide information about these Cooper pairs in an exciting type of superconductor that has only recently been discovered—a topological superconductor.

In conventional superconductors, Cooper pairs form due to interactions between the electrons and atomic vibrations, and they have a relatively simple symmetric geometry.

In contrast, the Cooper pairs in topological superconductors exhibit a more complex symmetry. "This symmetry in turn gives rise to special quantum states on the surface of the material known as Majorana fermions," explains Yamazaki.

First predicted by Ettore Majorana in 1937, the Majorana fermion is a particle that is identical to its antiparticle.

A pair of Majorana fermions appear on the surfaces of time-reversal symmetric topological superconductors. They are said to be 'time-reversal symmetric'—that is, they would behave the same if time were reversed. They are also characterized by an electromagnetic response that varies depending on direction, known as a Majorana multipole response.

But in a few special materials, Cooper pairs break this time-reversal symmetry so that Majorana fermions no longer form pairs.

"In time-reversal-symmetry-breaking topological superconductors, a single Majorana fermion appears on the boundary," says Yamazaki. "It doesn't interact with external fields because it's electrically neutral."

This lack of interaction with fields makes it difficult to probe these isolated Majorana fermions. To find a way to investigate them, Yamazaki and Kobayashi have theoretically extended the concept of Majorana multipole responses to time-reversal-symmetry-breaking topological superconductors.

In this way, they showed how the electromagnetic response of Majorana fermions can provide insights into the properties of the Cooper pairs in the underlying superconducting material.

"Our research has identified the fundamental electromagnetic properties of Majorana fermions in topological superconductors," says Yamazaki. "However, further investigation is required to explore their influence on actual physical quantities and to establish techniques for detecting them." ●

Reference

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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, 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 alongside the five Executive Directors of Science are the Promotion Division Directors.

Additionally, the President and Executive Directors engage with the Executive Directors of Science to do top-down reviews of the research domains and look at the challenges that RIKEN should pursue research on. At the same time, these leaders work to incorporate into management plans bottom-up perspectives from researchers working at the forefront of scientific research.

We asked about the goals of each domain from both researchers' and administrative departments' perspectives. →

This issue features three of the five domains. The other two domains and TRIP will be featured in the next issue.

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 (TRIP), gathered together in one place.

RIKEN'S ORGANIZATION

MATHEMATICAL, COMPUTATIONAL AND INFORMATION SCIENCE DOMAIN

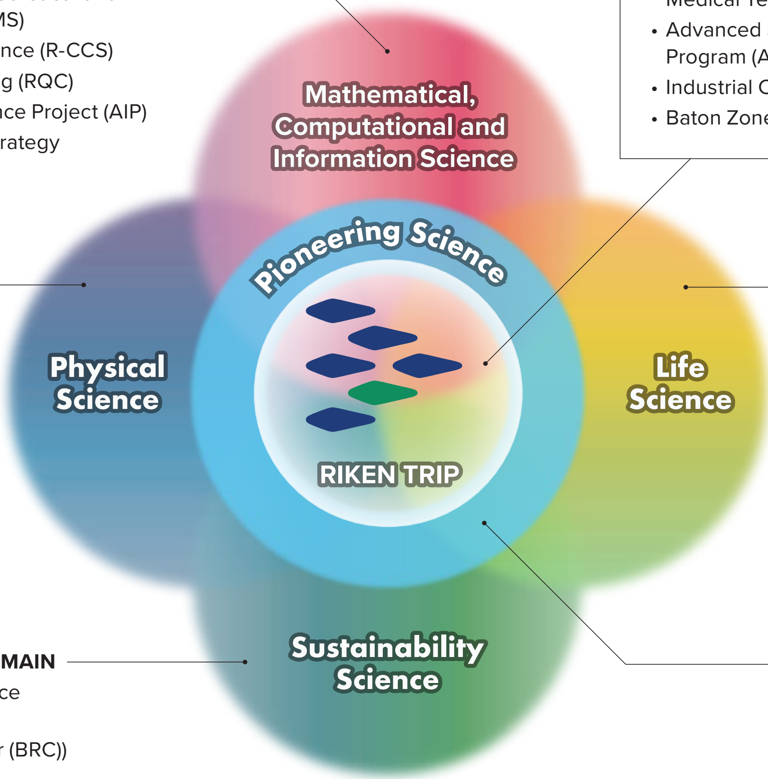
- Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS)
- Center for Computational Science (R-CCS)
- Center for Quantum Computing (RQC)
- Center for Advanced Intelligence Project (AIP)
- RIKEN Information R&D and Strategy Headquarters (R-IH)

TRIP INITIATIVE

- 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)

PHYSICAL SCIENCE DOMAIN

- Center for Emergent Matter Science (CEMS)
- Center for Advanced Photonics (RAP)
- Nishina Center for Accelerator-Based Science (RNC)
- SPring-8 Center (RSC)



LIFE SCIENCE DOMAIN

- Center for Integrative Medical Sciences (IMS)
- Center for Biosystems Dynamics Research (BDR)
- Center for Brain Science (CBS)
- BioResource Research Center (BRC)

SUSTAINABILITY SCIENCE DOMAIN

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

PIONEERING SCIENCE DOMAIN

- Pioneering Research Institute (PRI)

*TRIP (Transformative Research Innovation Platform of RIKEN platforms)

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 sustainable societies and achieve a balance between human society and the health of the planet by carrying out research and development related to the production of biological resources, material circulation, symbiosis, and the environment, with the aim of maintaining the Global Commons.

PHYSICAL SCIENCE DOMAIN

This domain aims to bring together diverse researchers and further 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.

DOING UNCONVENTIONAL SCIENCE

Over a century ago, Dr. Jokichi Takamine, who proposed the founding of RIKEN in Japan, declared that: "Japanese researchers must not simply imitate the West, but instead carry out research based on their own originality." This pioneering spirit remains at the core of RIKEN today. At the same time, today's RIKEN, as a national research and development agency, also carries out research in line with key national policies. Currently, RIKEN operates 22 research centers and other programs dedicated to advancing important fields deemed vital to the nation's progress.

NURTURING THE SEEDS OF FUTURE PROJECTS

The Pioneering Science Domain plays a key role in generating new research fields that may one day grow into large-scale national projects and evolve into full-fledged research centers. Researchers from diverse disciplines collaborate on long-term efforts to give form to new and as-yet-undefined ideas, constantly taking on challenges from a forward-looking perspective.

The sole center within the Pioneering Science Domain is the Pioneering Research Institute. This structure is rooted in RIKEN's unique system of "Chief Scientist Laboratories," which dates back to 1921 and laid the foundation for what RIKEN is today. Under this system—remarkable for its time—research themes, generous budgets, and personnel decisions were entrusted not to departments but directly to Chief Scientists heading individual labs. This revolutionary approach transformed RIKEN into a "paradise for scientists," fostering free and vigorous discussions that gave rise to groundbreaking ideas.

I served as an Executive Director of RIKEN from 2017 to 2022. What struck me most during that time was RIKEN's steadfast commitment to the pioneering spirit—its firm stance that "we do not pursue research that anyone could achieve given enough time and money; we pursue ambitious research." I want to help create mechanisms that preserve and strengthen this spirit.

At the Pioneering Research Institute, researchers from various fields come together, serving as bridges across different areas of study. This role is quite similar to that of the TRIP Headquarters, which also aims to foster "science that connects" across disciplines. My understanding is this: TRIP provides a platform under which researchers gather around clearly defined, crucial themes to advance joint projects. The Pioneering Science Domain, on the other hand, is a space where diverse individuals engage in ongoing dialogue across fields, each striving to create new, unconventional forms of science. Both approaches are essential for scientific progress.

I am a mathematician. At Tohoku University, I also served as Director of the Advanced Institute for Materials Research—perhaps an unexpected appointment, given my background. There, researchers in metallurgy, applied physics, chemistry, life sciences, and other disciplines work together to develop materials with exceptional functionalities. When I was first asked to lead the institute, I hesitated. But mathematics is often described as the universal language of science. It helps articulate tacit knowledge—what researchers grasp intuitively—in a way that can be shared with others. It connects disciplines and contributes to the advancement of science. This role allowed me

MOTOKO KOTANI

Executive Director of Science, Pioneering Science Domain to put that belief into practice, and I hope to bring that same experience and perspective to my work here as well.

SCIENCE IS FUTURE-ORIENTED—AND IT IS SHAPED BY THE YOUNG

The world is undergoing profound transformations. Science itself—now larger in scale and more complex than ever—is experiencing a kind of tectonic shift. Traditional disciplines are merging and giving rise to entirely new forms of science. At the same time, expectations toward science and technology are becoming more diverse, and meeting these expectations requires a corresponding diversity in scientific approaches.

We are now being called upon to pioneer new fields by encouraging encounters among researchers from different disciplines. International collaboration is also more important than ever. Science, by its very nature, is future-oriented—and it is something to be created by the younger generation. I want to help create an environment where ambitious ideas can flourish—ideas so bold that people will say, "That's impossible!"—and where young scientists are empowered to take on such challenges.

KOKI SORIMACHI

Division Director, Pioneering Science Promotion Division

Unlike working at a research center with a clearly defined field of study, this domain brings together researchers from entirely different backgrounds—it's a space where the outcomes are unpredictable. At first, it was a real challenge just to keep track of who was working on what. But having been involved in the predecessor of this domain, I'm fully committed to supporting it with everything I've got.

TETSUO HATSUDA

Executive Director of Science, Mathematical, Computational and Information Science Domain

PIONEERING THE FUTURE THROUGH THE SYNERGY OF MATHEMATICS, COMPUTATION, AND INFORMATION SCIENCE

Before taking my position as Chief Scientist at the RIKEN Nishina Center for Accelerator-Based Science in 2012, I taught at various universities, including the University of Tokyo. As a university faculty member, opportunities for cross-disciplinary discussions about science were limited due to the constraints inherent in academic departments.

However, the classification of natural sciences, humanities, and social sciences into separate disciplines is ultimately a matter of human convenience; in essence, there should be no clear boundaries in academia. In this regard, RIKEN—where research is placed at the core and where researchers from a wide range of fields gather—provides fertile ground for natural cross-disciplinary exchanges. It is also home to many world-leading researchers. Furthermore, in order to support large-scale computation and data analysis, RIKEN has established cutting-edge research infrastructure such as the supercomputer Fugaku and the quantum computer A.

Amidst the transformation of traditional academic frameworks, the Mathematical, Computational, and Information Sciences Domain, which comprises over 1,000 internationally diverse researchers, is working to build a computational and information foundation that can support all fields of science and technology. At the same time, it aims to foster the creation of new and innovative fundamental theories through collaboration with academia and industry.

FOSTERING A FERTILE GROUND FOR TRANSCENDING DISCIPLINARY BOUNDARIES

In this domain, four research centers and the RIKEN Information R&D and Strategy Headquarters (R-IH) are working in cooperation to promote the integration and convergence of mathematical, computational, and information sciences. Their collective efforts are driving the creation of new foundational theories, significantly expanding the scope of the computable domain, and accelerating the application of AI technologies to scientific research—an initiative known as "AI for Science". By extending these advances to other research fields, the ultimate aim is to contribute to the dramatic advancement of scientific discovery.

The RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS) is a globally unique organization where young researchers from diverse fields—including mathematics, physics, chemistry, life sciences, computational science, and information science—gather "under one roof" to engage in open and interdisciplinary dialogue. The center also applies mathematical perspectives to the humanities and social sciences, while fostering the next generation of mathematical talent through collaborations with universities and research institutions in Japan and abroad.

At the RIKEN Center for Computational Science (R-CCS), the world-class supercomputer Fugaku is being utilized across a wide array of research domains. The center operates in a trinity of supercomputing, quantum computing, and AI, aiming to realize "science of computation, by computation, and for computation." Through this approach, R-CCS is laying the groundwork for AI for Science, seeking to give rise to new scientific disciplines from within existing ones.

The RIKEN Center for Quantum Computing (RQC) is conducting foundational research to develop and enhance the performance of quantum computers based on various architectures. By integrating these efforts with computational science and electronics technologies, the center is working toward establishing next-generation quantum computing technologies. It also serves as a core hub for quantum technology innovation in Japan, conducting collaborative research with universities, research institutions, and industries both domestically and internationally.

The RIKEN Center for Advanced Intelligence Project (AIP) is pursuing cutting-edge research in machine learning and optimization, aiming to gain an understanding of their underlying principles and develop foundational technologies for safe and trustworthy AI that can be applied universally in real-world settings. In addition to promoting practical applications that address societal issues and accelerate scientific research, AIP also actively tackles social challenges such as AI safety, ethics, and governance.

FULLY RESPECTING THE INDIVIDUALITY OF EACH RESEARCHER

Looking back at the history of science, many unexpected discoveries and groundbreaking technologies have emerged as researchers pursued their own intellectual curiosity. We believe that it is the mission of this research field to carefully nurture the seeds of new science that grow in a free research environment—one that fully respects individual uniqueness—and to connect those seeds to a better future for humanity and the planet.

HIROTAKA SHIBATA

Division Director, Mathematical, Computational and Information Science Promotion Division

Going forward, we will strive to ensure that the research outcomes generated in this domain contribute tangibly to solving societal challenges, through a united effort in which researchers and administrative departments function as two wheels of the same cart. To achieve this, we will further strengthen and deepen the collaboration among administrative teams more than ever before.

FROM BIRTH TO AGING: UNRAVELING THE MYSTERIES OF LIFE

In the 20th century, it was still possible to achieve significant breakthroughs in life science through individual efforts. However, uncovering the complexities of life as a system requires teamwork that harnesses each researcher's ideas and curiosity. Today, life science has evolved into an interdisciplinary field that goes beyond biology, incorporating computational science and engineering. A pressing issue in life science now is how to effectively leverage the current dramatic advances in AI.

In 2018, I joined RIKEN as the Director of the Center for Biosystems Dynamics Research, where I studied aging and lifespan using model organisms such as nematodes and small fish. Although Japanese people are known for their longevity, the average healthy lifespan—years spent in good health—is significantly shorter than the average life expectancy: by about nine years for men and twelve years for women. This gap presents a major societal challenge.

AIMING TO EXTEND THE HEALTHY LIFESPAN

The life sciences domain at RIKEN, which is composed of four research centers, has adopted the concept of "Total Life Science." This encompasses research spanning the entire human lifecycle from birth to aging, focusing on physical and mental health, the causes of diseases, and their treatments. Leveraging RIKEN's comprehensive strengths in computational science, AI, and robotics, we aim to contribute to extending the healthy lifespan, creating innovative drug discovery and medical technologies, and addressing societal challenges such as Japan's declining birthrate and aging population. Also, with the growing emphasis on planetary health—balancing the health of people and the Earth—we are promoting research on the interactions between environmental and genetic factors in life phenomena. To achieve this, we are also deepening collaborations with universities and industry.

EISUKE NISHIDA

Executive Director of Science, Life Science Domain

The Center for Integrative Medical Sciences (IMS) contributes to the development of new drugs and therapies for immune and allergic diseases. Precise measurement of molecular and cellular behaviors and integrated "cross-organ" analyses that consider multiple organs as a total system are crucial.

The Center for Biosystems Dynamics Research (BDR) aims to comprehensively understand the life cycle from birth to death using mathematical models and to reproduce biological phenomena using organoids (mini-organs), while developing foundational technologies to control these processes. This approach is expected to help extend the healthy lifespan.

The Center for Brain Science (CBS) focuses on exploring the essence of the "mind." What distinguishes humans from other animals is the mental activity represented by intelligence, sensibility, and sociality. Understanding the mind also aids in elucidating behavioral patterns. Researchers at the center also search for diagnostic and therapeutic methods for mental and neurological disorders.

The RIKEN BioResource Research Center (BRC) collects, preserves, and distributes a vast array of animals, plants, microorganisms, and cells under world-class quality control and cultivation technologies. It maintains one of the largest collections of mouse strains worldwide. Since research involving humans poses ethical challenges, these experimental animals are indispensable for learning how to overcome diseases. Having our own bioresources strengthens our research foundation and further enhances our added value.

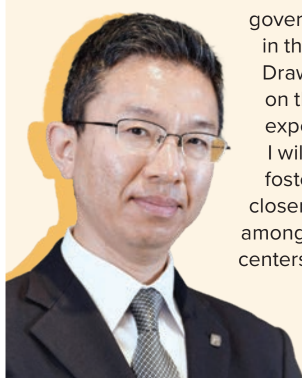
ACTING AS A CATALYST FOR INTEGRATING FIELDS

Many researchers belonging to the four centers have produced world-class achievements. The advent of AI marks a major turning point in life sciences, and the launch of this cross-disciplinary domain is timely. As the overall director of the domain, I strive to serve as a "catalyst," ensuring that the sum of "1 + 1" becomes not just 2, but 3 or even 4. I respect each individual's free ideas and am committed to helping them fully realize their potential.

MITSUTAKA NAGANO

Division Director, Life Science Research Promotion Division

RIKEN has participated in large-scale international projects such as the Human Genome Project. Our goal as a domain is to leverage the scale advantages to continuously tackle major scientific challenges such as achieving healthy life cycles. The four centers are geographically spread across Wako, Tsukuba, Yokohama, and Kobe, each having developed close relationships with local universities and governments in the region. Drawing on this experience, I will support fostering closer ties among the centers.



Could caterpillar guts help to manufacture nanomaterials?

The tobacco cutworm (pictured) possesses very powerful gut enzymes. Later in life, these larvae turn into large, hungry moths that eat and damage crops across Asia and Oceania.

Chemists swap flasks for the intestines of larvae to modify nanocarbon belts, revealing a new route to chemical synthesis.

This feature looks at the work of

KENICHIRO ITAMI

Kenichiro Itami completed his PhD in chemistry at Kyoto University in Japan in 1998. Since 2012, in tandem with other work, he has served as director of the Institute of Transformative Bio-Molecules (ITbM Nagoya University). Since 2019, he has also been a Research Fellow at the Institute of Chemistry, Academia Sinica, Taiwan. Between 2013 and 2020, he was the research director of JST-ERATO Itami Molecular Nanocarbon Project. In April 2024, Itami assumed the position of chief scientist at the RIKEN Pioneering Research Institute, and also became the team director of the RIKEN Center for Sustainable Resource Science in April 2025. His research focuses on the development of innovative functional molecules, including structurally uniform nanocarbons.

Making new nanomaterials could be as easy as giving caterpillars nanocarbon belts to nibble on and then processing their poo, RIKEN chemists have discovered[1]. This surprising discovery could pave the way for totally new chemical synthesis methods in the lab.

When he started out as a researcher, Kenichiro Itami never envisioned that one day he would be scraping up and using caterpillar droppings. That's because he's not a biologist, but a chemist specializing in minuscule rings and carbon nanobelts. But innovative research often involves thinking outside the box.

The team at the RIKEN Molecule Creation Laboratory is studying the building blocks of carbon nanotubes, which are nanometer-scale cylinders of carbon atoms that can be used to create light-weight materials notable for their strength and electrical conductivity.

Itami's team usually synthesizes these carbon 'nanobelt' and 'nano-ring' components in a pristine chemistry lab using high-purity chemicals and squeaky-clean flasks. For example, they recently used conventional chemistry to add sulfur-containing functional groups to carbon nanobelts to create strong and light nanomaterials with useful semiconducting and fluorescence properties (see page 15)[2].

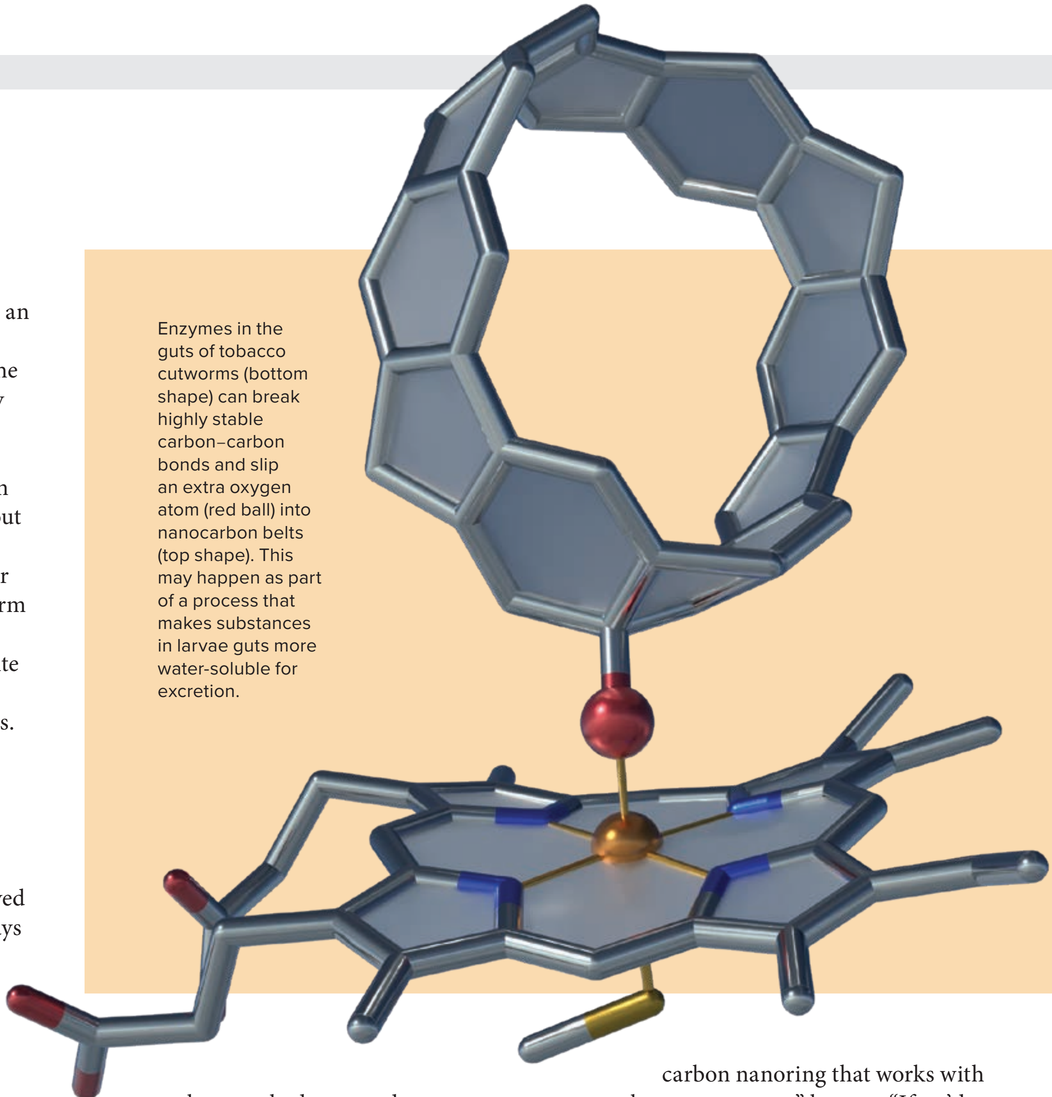
UNCONVENTIONAL PLAN

But one day, inspired by conversations on so-called 'xenobiotic metabolism' with some of his team members who have a background in biology, Itami had an outlandish idea—what would happen if he used insects to synthesize chemicals? Rather than trying to make new forms of carbon nanobelts via more traditional lab-based methods, could he feed carbon nanobelts to caterpillars and then look at what comes out of the other end?

Xenobiotic metabolism is a process whereby living organisms modify foreign chemicals, such as drugs or pollutants, to make them more water soluble for excretion. "For organic chemists like us, using insects for chemical synthesis was an unbelievably crazy idea," Itami admits.

The results were very disappointing the first time his team tested their idea: they ended up with a lot of dead caterpillars. They had fed silkworms a diet of boiled kidney beans and agar laced with carbon nano-rings, but the nano-rings turned out to be toxic to the caterpillars.

The team then decided to try a hardier species of caterpillar, the tobacco cutworm (or cotton leafworm). These larvae turn into large moths with a voracious appetite that are a pest across Asia and Oceania, damaging economically important crops. Moreover, they are reported to possess roughly twice as many detoxifying enzymes as domestic silkworms.



Enzymes in the guts of tobacco cutworms (bottom shape) can break highly stable carbon–carbon bonds and slip an extra oxygen atom (red ball) into nanocarbon belts (top shape). This may happen as part of a process that makes substances in larvae guts more water-soluble for excretion.

'TOTALLY UNEXPECTED'

This time most of the caterpillars survived — and the team got a shock after two days when they collected the droppings and extracted and purified the chemicals within them. X-ray diffraction revealed that the caterpillars had slipped an oxygen atom into many of the carbon nanobelts. The researchers were able to deduce by increases in metabolism-related gene expression that a group of gut enzymes that modifies chemicals for excretion was responsible. They confirmed their finding by grafting the gene for these enzymes into *Escherichia coli* bacteria and then observing the same reaction with the carbon nanobelt.

Strikingly, the reaction that inserted the oxygen atom involved breaking a highly stable carbon–carbon bond, which usually requires a lot of energy. It would be challenging to make the same chemical in a lab using conventional methods, says Itami.

"That was totally unexpected," he recalls. "When we saw this result, we were like 'wow!' and the lab was full of excitement."

Although the resulting oxygen-containing carbon nanobelt currently lacks known industrial applications, the experiment highlights the promise of insects as novel tools for chemical synthesis.

"We've demonstrated the potential of 'in-insect' synthesis for producing entirely new molecules," Itami says.

The tobacco cutworms also produced the compound in much higher quantities than the team had expected.

"We initially had isolated yields of about 1%, which was already a lot, because we didn't expect high-yielding reactions within an insect. But later we got close to yields of 10% by optimizing feeding concentrations and the purification process," says Itami, who notes that the yields could potentially be improved further.

ZERO TO HERO

The team used carbon nanorings made up of six benzene rings in their initial experiments. But when they repeated the experiment with rings with five, seven, eight, nine, ten, eleven or even twelve benzene rings, nothing happened. Itami suspects this is because enzyme activity is highly selective, and dependent on very specific chemical structures.

There was an element of serendipity involved in the discovery, as the team had never attempted anything like this before, Itami notes.

"In retrospect, we were pretty lucky to be able to discover this reaction, because we just happened to start with the one carbon nanoring that works with tobacco cutworms," he says. "If we'd started with one of the other nano-rings, we wouldn't have seen any reaction and might have given up."

The team is now experimenting to see if they can use different types of insects besides caterpillars to synthesize chemicals. "Other researchers become extremely excited when I present this work at conferences, and tend to ask 'what about using cockroaches or grasshoppers?'," Itami says. "That's something we're looking into now."

For Itami, one of the most appealing aspects of the discovery was that a notorious pest can have uses in the lab. "Tobacco cutworms are a serious pest that everybody wants to eliminate," he says. "But while they are the bad guys for others, they became the heroes in our study." ●

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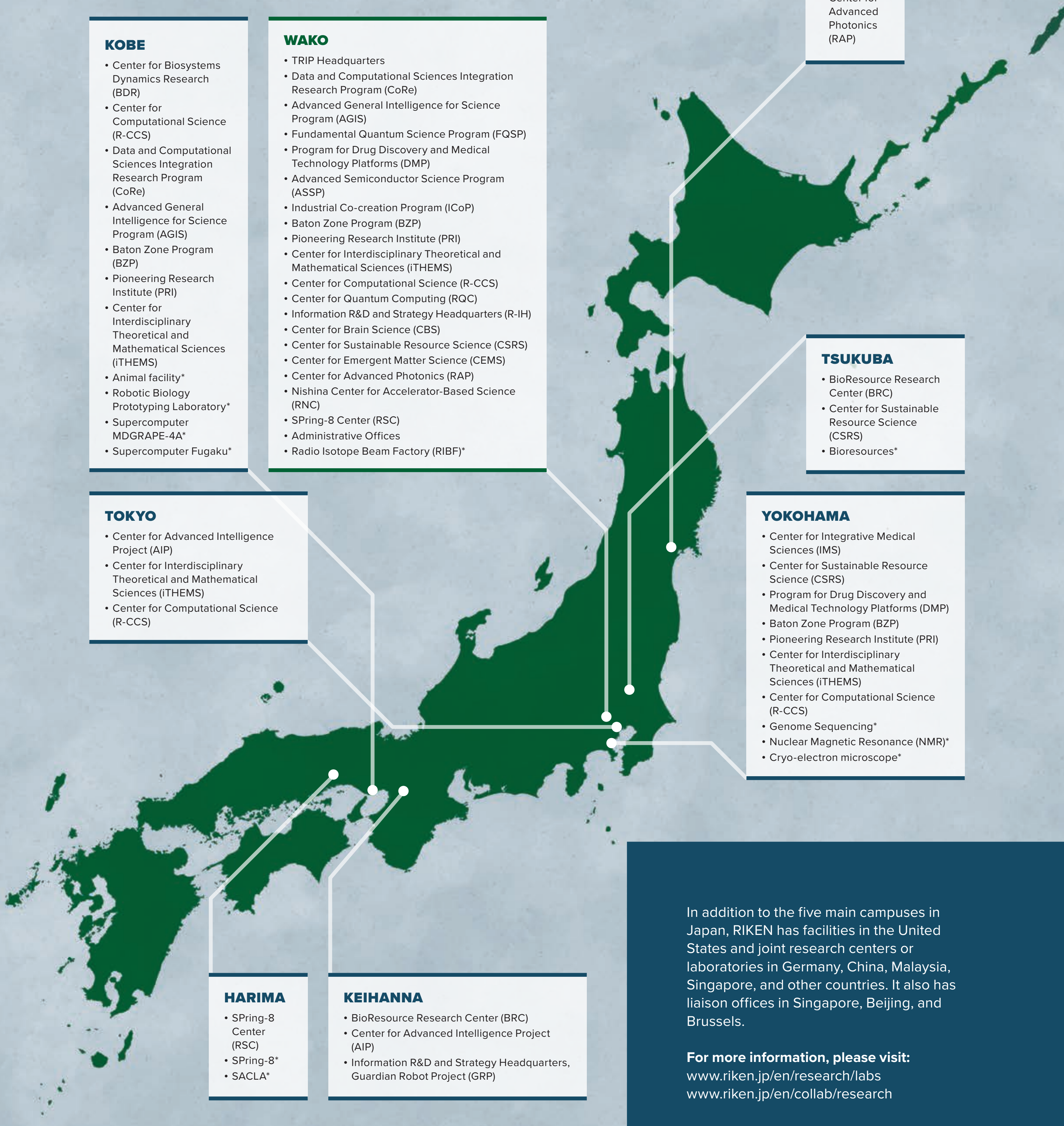
2. Shudo, H., Wiesener, P., Kolodzeiski, E., Mizukami, K., Imoto, D. *et al.* Thiophene-fused aromatic belts. *Nature Communications* **16,** 1074 (2025).

RIKEN'S CENTERS AND FACILITIES

*Denotes large research infrastructure



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)
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- Nishina Center for Accelerator-Based Science (RNC)
- SPring-8 Center (RSC)
- Administrative Offices
- Radio Isotope Beam Factory (RIBF)*

SENDAI

- Center for Advanced Photonics (RAP)

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 the five main campuses in Japan, RIKEN has facilities in the United States and joint research centers or laboratories in Germany, China, Malaysia, Singapore, and other countries. It also has liaison offices in Singapore, Beijing, and Brussels.

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