Institute for Integrated Cell-Material Sciences

iCeMS

Our World, Your Future

Kyoto University
Institute for Advanced Study

Vol. 6
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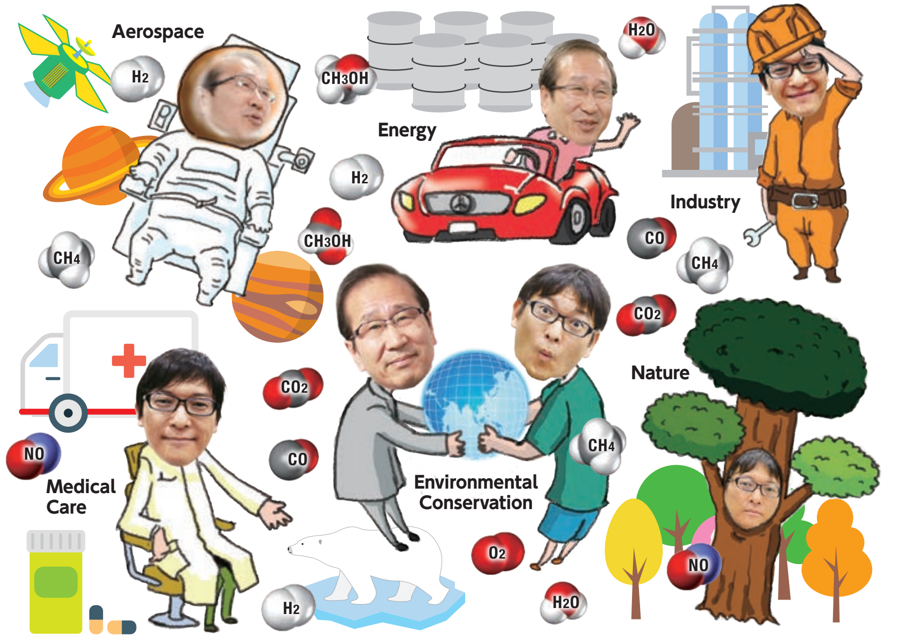
contents

A structural model of a porous coordination polymer, as published in 1997. Kitagawa realized a stable polymer structure that could withstand the removal of solvent molecules from its micropores and the introduction of methane or other gases. Turn to page 7 to read the full story.

Feature Micropores are Here to Help! Welcome to the World of PCP/MOFs

The discovery of porous coordination polymers (PCP/MOFs) in 1997 by Susumu Kitagawa, now the director of iCeMS, was a breakthrough in materials science. With innumerable micropores arrayed in regular patterns, these materials have the potential to transform many aspects of our lives, ranging from environmental protection, energy, medicine, aerospace and manufacturing. In this article, two leading researchers will guide us into the World of PCP/MOFs.

Realms Where PCP/MOFs (may) Have Significant Roles



Still rather young at age 20, PCP/MOFs have strong growth potential

Let's explore the PCP/MOF world together !

Susumu Kitagawa
Director

Foremost PCP/ MOF Researcher

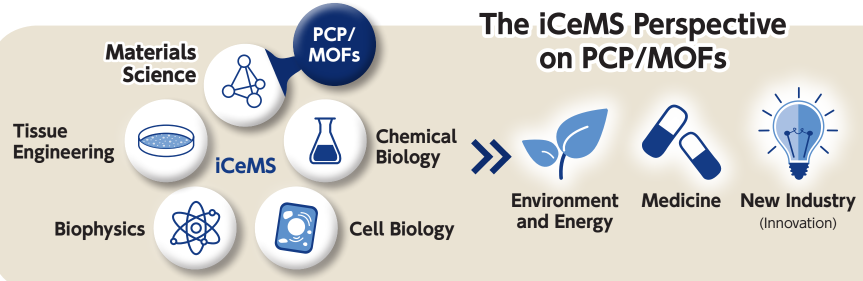
Masakazu Higuchi
Program-Specific Assistant Professor

Aiming to create as-yet unknown value with PCP/MOFs

Susumu Kitagawa Born in 1951 in Kyoto. Received a PhD in Chemistry from the Graduate School of Engineering of Kyoto University. Held the positions of Associate Professor at the Faculty of Science and Engineering of Kindai University, Professor at the Department of Chemistry of Tokyo Metropolitan University, Professor at Graduate School of Engineering of Kyoto University, and Professor at iCeMS. Has been the Director of iCeMS since 2013. He was selected as a Thomson Reuters Citation Laureate in 2010, and received the Medal with Purple Ribbon in 2011.

Masakazu Higuchi Born in 1975 in Kochi, Japan. Completed his PhD in chemistry at the Graduate School of Engineering of Kyoto University in 2005. Held positions at RIKEN and the University of Tokyo, and has been at his present position since 2010. Started the venture company Atomis Inc. in 2015 aiming to accelerate the practical application of PCP/MOFs. Also enthusiastically engages in activities to communicate information about science-business related topics to the public and children.

The iCeMS Perspective on PCP/MOFs



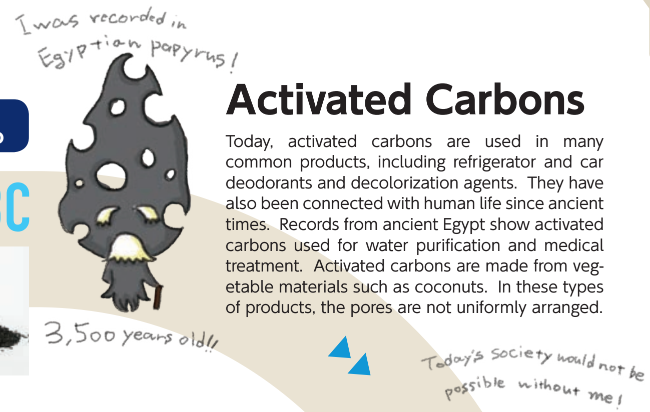
iCeMS is an interdisciplinary group of cell biologists, chemists and physicists, working from many viewpoints to address contemporary problems, such as global warming, pollution, disease and aging. Currently within the field of materials science, PCP/MOFs have the potential to intersect with various fields in the future.

The History of Porous Materials

PCP/MOFs are a type of porous material. As the name suggests, porous materials contain empty spaces. Riddled with innumerable micropores, these materials may seem unserviceable at first glance, but, in fact, they have long been utilized in familiar ways. The following are some examples of porous materials, with a review of their history.

Approx 3500 years ago

1500 BC



Activated Carbons

Today, activated carbons are used in many common products, including refrigerator and car deodorants and decolorization agents. They have also been connected with human life since ancient times. Records from ancient Egypt show activated carbons used for water purification and medical treatment. Activated carbons are made from vegetable materials such as coconuts. In these types of products, the pores are not uniformly arranged.

Approx 260 years ago

1756 Discovered in natural rock

1862 Composed artificially

Zeolite

Zeolites are a type of microporous mineral that exhibit roughly 220 different structural frameworks. Their uses include catalysis, ion exchange and gas purification, and they are especially important in petrochemical manufacturing. Zeolites have a very rigid structure made up mainly of silicon, aluminum and oxygen, with regularly arrayed micropores. Although the mineral framework can differentiate molecules by size, it cannot differentiate molecules close in size with similar properties. For this reason, it is difficult to use zeolite for precise adsorption and separation.

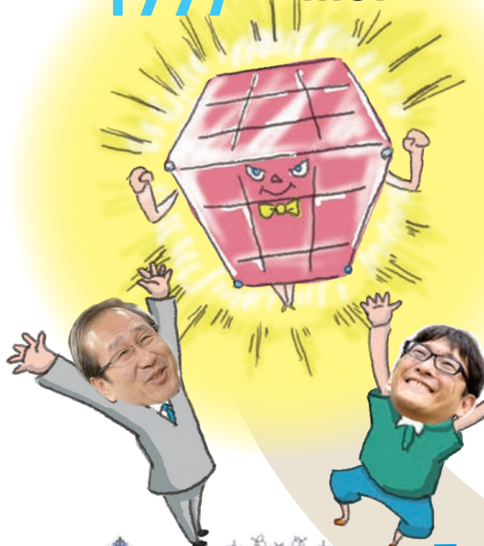
Although activated carbons and zeolites are indispensable for modern life, materials with even greater performance and energy efficiency are still needed. Enormous amounts of energy are consumed in daily life, transport, manufacturing and other industries, and of this, 14% is spent on the separating chemical products. Development of porous materials may be the key to reducing the energy requirements for efficient storage, separation or conversion of target chemicals (gases and small molecules). (See page 5.)

Meanwhile, an innovative material has appeared. The name is...

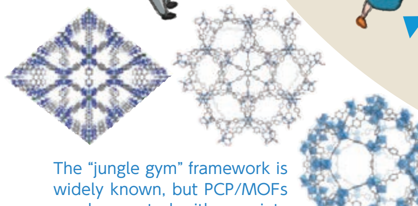
20 years ago

1997

PCP : Porous Coordination Polymer
also known as
MOF : Metal Organic Framework



Porous coordination polymers (PCP/MOFs) are materials discovered by Professor Susumu Kitagawa. Containing innumerable micropores of uniform size, they can take in many times more molecules than activated carbons and require little energy for efficient separation performance. In addition, they have 100 times more variations of pores than zeolite. Pore size and characteristics can be freely controlled by a combination of metal ions and organic ligands. Research on these materials began a mere 20 years ago, and further applications are expected expand into a wide range of fields.

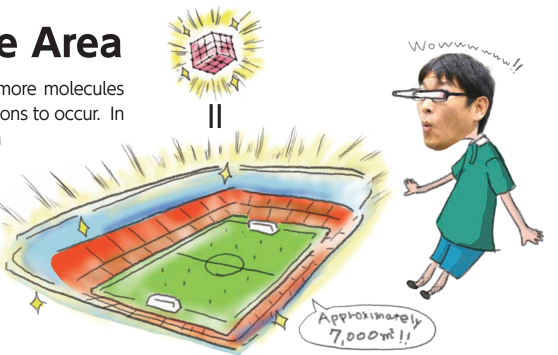


The "jungle gym" framework is widely known, but PCP/MOFs can be created with a variety of structural appearances.

Properties of PCP/MOFs

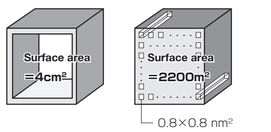
Porous coordination polymers are attractive materials that bring together all of the advantages of preexisting porous materials. Introduced here are three key properties that reveal the secrets of their performance.

• Large Surface Area



The larger the surface area, the more molecules adsorbed and the easier for reactions to occur. In other words, larger surface area means higher performance. Activated carbons also have large surface area, but they can't match PCP/MOFs. A single gram of MOF material has a total surface area comparable to a soccer field!

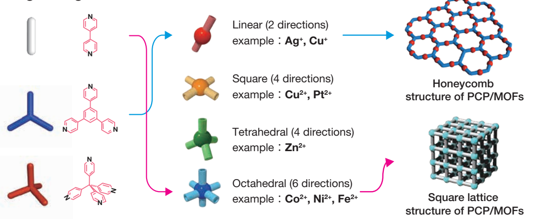
In the case of a one-centimeter cube



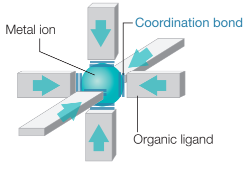
Imagine a cube that is one centimeter on each side. If a hole of 1 cm² is bored through it, four internal surfaces will form. In this case, the surface area would be 4 cm². Now imagine that a series of tiny holes, measuring one nanometer on each side, are drilled through that same one-centimeter cube. The interior surface area would be tremendously increased. Each pore hole is very small, but PCP/MOFs contain an enormous numbers of them.

• Designability

PCP/MOFs are a continuous series of "metal complexes", in which metal ions and organic ligands are connected by coordinate bonds. There are about 30 kinds of metal ions, and innumerable kinds of organic ligands, presenting limitless possible combinations. To date, 23,000 variations on the basic framework have been created, which represents a mere 20 years of research. As you read this, new PCP/MOFs may be newly synthesized in some laboratories.



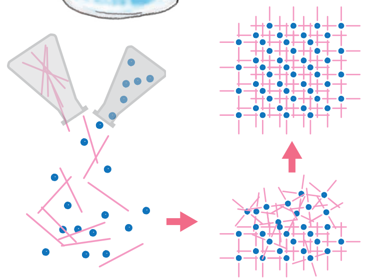
Metal ions are connectable in different directions, depending on their type. Some can connect in two directions, others in four directions. As the metal ions connect to both ends of organic ligands, a huge variety of structures is possible.



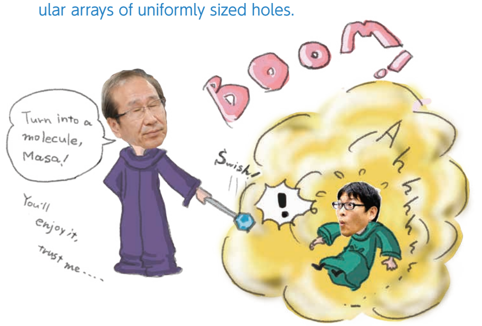
With coordinate bonds serving as the adhesive, metal ions are linked with organic ligands to form a metal complex.

• Ease of Fabrication

How do we actually make PCP/MOFs with metal complexes in endless series? The answer is simple: Mix an organic ligand solution with a metal ion solution. That's all there is to it. Information is added, based on a design prepared in advance to instruct the ions to connect with both ends of the ligands. From this, the material is automatically generated.

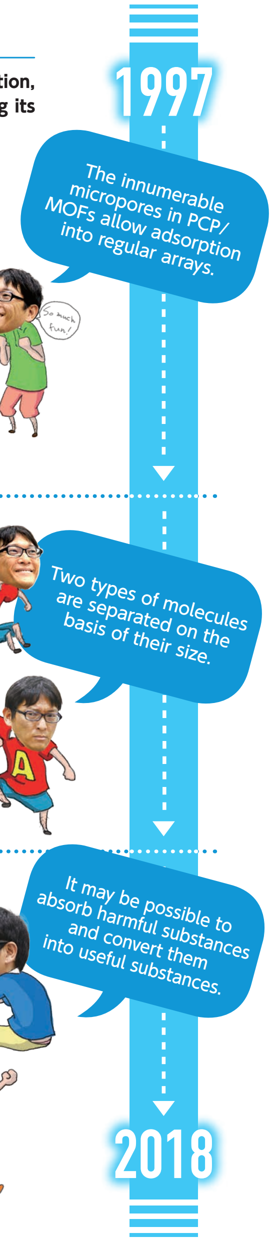


When metal ions are mixed with organic ligands, they link into chains of coordinate bonds, instantly forming a polymer structure with regular arrays of uniformly sized holes.



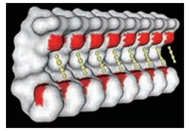
What Can PCP/MOFs do? —— Research Trends

PCP/MOF material development could not be described without mentioning three key functions: (1) Storage, (2) Separation, (3) Conversion. The main research development has focused on these three functions since work started in 1997. Tracing its history, the field has shifted over time from simple to complex research, as scientists took on ever greater challenges.

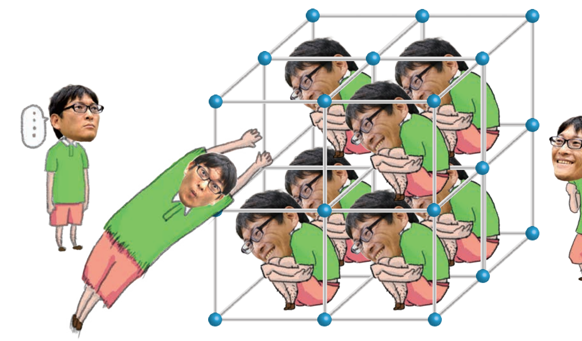


❶ Storage

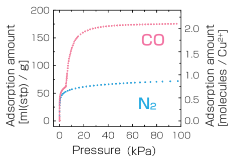
Pores in PCP/MOFs will adsorb and hold large quantities of molecules. A great deal of research has looked at the adsorption of hydrogen, methane, carbon dioxide and other gases, all for the ultimate purpose of storage. Early PCP/MOF research focused on storage considerations, such as how to maximize the number of molecules adsorbed and how to minimize the space needed to hold them.



Acetylene molecules arrayed in orderly fashion inside PCP/MOFs. The pressure can build to 2 atm, a level with high risk of explosive reaction. PCP/MOFs, however, enable stable storage.

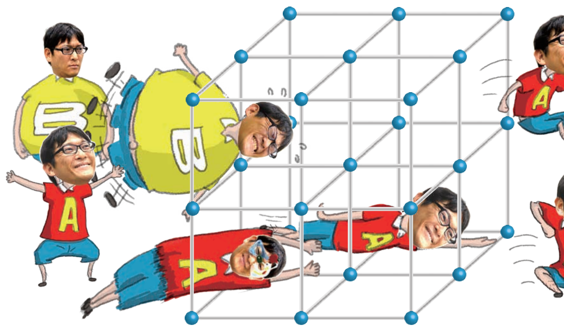


❷ Separation



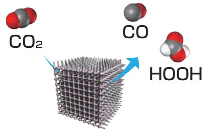
Even molecules of similar size and similar properties can be efficiently separated in PCP/MOFs.

In substances containing several kinds of molecules, one molecule can be selected for adsorption into PCP/MOFs. In activated carbon, the pores are not of uniform size, so various different molecules will be adsorbed at the same time. In PCP/MOF material, where the holes are all the same size, only a single target substance is adsorbed, producing outstanding separation performance.

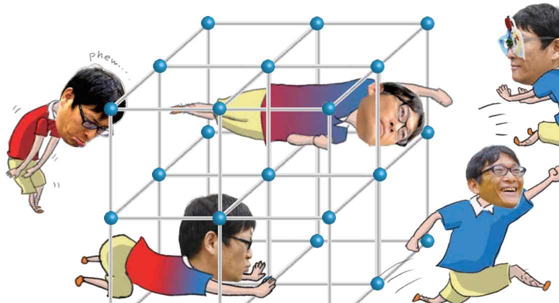


❸ Conversion

One kind of molecule adsorbed into PCP/MOFs can be converted into a different type of molecule. When a highly reactive metal ion is incorporated in the framework of the material, it can work as a catalyst, stimulating a chemical reaction that converts the adsorbed molecules into another kind of molecule. An as-yet unobtained goal using this method is the conversion of environmentally harmful substances into useful substances. One such nuisance molecule is carbon dioxide, which causes global warming and abnormal weather patterns. PCP/MOF materials present a hope for some sort of alchemical miracle, such as converting carbon dioxide to methane.



When carbon dioxide comes into contact with PCP/MOFs structured with the right catalyst, it is converted into carbon monoxide and formic acid.



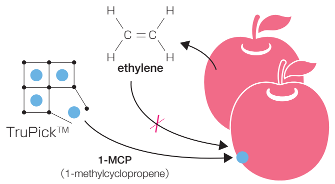
Real-Life Applications of PCP/MOFs

Practical utilization of PCP/MOFs has so far been limited to only a few fields, but an enormous potential for crossover into other fields exists.

Two Commercial Examples

TruPick™ [MOF Technologies, United Kingdom]

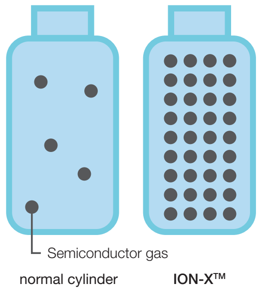
September 2016 The world's first commercial PCP/MOF product



Currently, approximately 40% of fruit spoils between the harvest and the consumer. This is because fruit releases ethylene, which adheres to the fruit surface and accelerates ripening. TruPick™ is a packaging product that releases 1-methylcyclopropene (1-MCP), a chemical that inhibits the production of ethylene. It utilizes water-sensitive PCP/MOFs, breaking down when contacting moisture in the fruit. This causes 1-MCP to adhere to the packaged fruit, slowing ripening and decay and preserving freshness during transport and storage.

ION-X™ [NuMat Technologies, USA]

October 2016 Safe transport of hazardous gases



ION-X™ is a compressed gas cylinder that utilizes PCP/MOF storage functionality. A special kind of PCP/MOFs placed inside the cylinder allows gas storage at pressures several times lower than normal atmospheric pressure. If hazardous gases are stored at high pressure, they may leak out of the cylinder, an extremely dangerous event. By reducing pressure, ION-X™ enables safe transportation. NuMat Technologies is developing a gas delivery business serving semiconductor factories in South Korea.

Further promise . . .

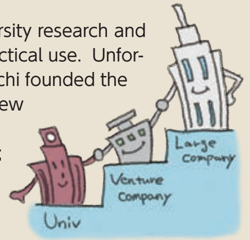
R&D for Innovative Filters

March 2018 Joint R&D by Dr. Higuchi and a company in Kyoto

Various deodorant products have long helped eliminate the unpleasant odors of toilets, tobacco smoke, etc. However, existing products do not remove all the odor molecule, leaving a portion of the unwanted smell. Dr. Higuchi from iCeMS, working together with Ohara Paragium Chemical Co., Ltd. is developing PCP/MOFs capable of instantly and completely eliminating odors. Still in the development stage, this work could lead to more comfortable living and work space in the near future.

Venture companies connecting universities and large companies

Venture companies play two roles in developing new materials: creating materials by applying basic university research and providing materials to large companies. To date, many venture companies have put new materials into practical use. Unfortunately, in Japan, there is not much of a mechanism for relating basic research to society. In 2015, Dr. Higuchi founded the venture company, "Atomis Inc.", which specializes in mass production of PCP/MOFs and the creation of new materials. The company has tried to be a bridge between universities and large companies.
Universities are responsible for fundamental research; venture companies are responsible for the "bridge"; and large companies are responsible for wide distribution. To develop new materials, these three roles are indispensable. In developing new materials, it is essential that people with diverse backgrounds approach the same goal by using their diverse strengths.

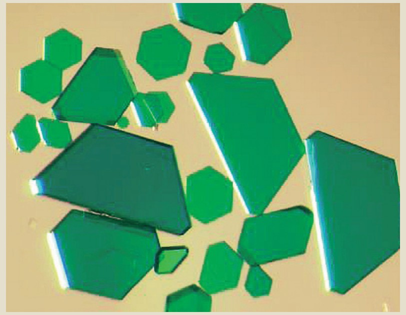


"I urge young researchers to step up, claim a new field, and announce it to the world. Open an unexplored area of research and challenge others to join in. You may feel the exhilaration of a pioneer watching the growth of a new frontier." Such is the advice of iCeMS Director Susumu Kitagawa, who himself opened a new frontier in materials science with the development of next-generation porous materials. Although now widely recognized as a field with high potential, when Kitagawa first published his work on porous materials, he was seen as a maverick. On a hunch, he took a new direction that interested him, and he found a gold mine.

Potential for a New Kind of "Empty Space"

Susumu Kitagawa Director of iCeMS

To date, there are about 9,000 papers regarding porous materials published each year, many dealing with transition metal ions. When Kitagawa started his work, Cu$^+$ was regarded as a completely insignificant ion. There are two types of charged copper ions, a +1 charged ion, Cu$^+$, and an oxydized form of +2 charged ion, Cu^{+2}. At that time, Cu^{+2} was amply researched, but no one took no notice of the Cu$^+$ ion. Both colorless and non-magnetic, it was seemingly without utility.



Photomicrograph of a porous coordination polymer crystal, published in 2014. Viewed on the nanometer level, the structure resembles that of a bamboo basket. It can be used to separate carbon monoxide out of a mixture of carbon monoxide and nitrogen, a task otherwise extremely difficult.

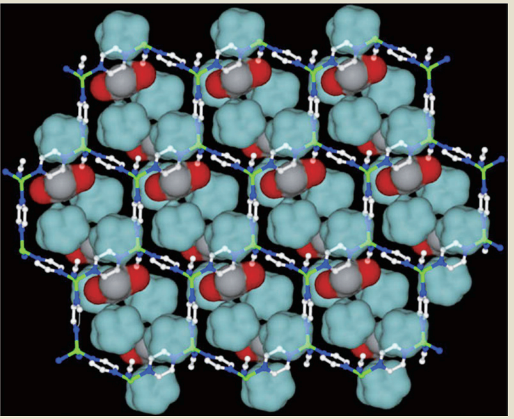
The "Insignificant Ion" that Astonished the World

After completing graduate work in quantum chemistry at Kyoto University, Kitagawa joined the science faculty of Kindai University as an assistant professor. "That is where I encountered coordination chemistry and started studying the coordination polymers that are constructed from organic ligands and metal ions." Materials that are constructed from organic ligands and metal ions have long been investigated for their electrical conductivity, which can enable a wide range of applications as nanometer-sized wires and electrocatalysts. It was an area that drew

Career summary on page 2

many competing researchers.

The metal ion that attracted Kitagawa's attention was Cu^{+}, which exhibits a spherical electron configuration. While the Cu^{+2} ion binds to organic ligands to give a directionally extended structure, the Cu^{+} ion can form three-dimensionally extended structure. Because of its spherical electron configuration, it readily forms crystals with minimal distortion. "I realized that when Cu^{+} ions are bound to organic molecules, they provide a regular, continuous crystal. I thought this must be useful, so I kept studying it. However, the different electronic structures of metal ions and organic molecules hardly made electron conducting band structures. I kept racking my brain, but I couldn't get the results I was hoping for."

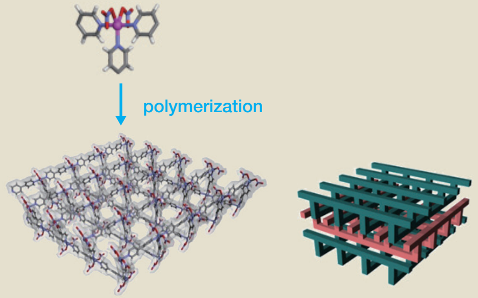


The crystal structure of a porous honeycomb-type coordination polymer as discovered by Kitagawa and his students during computer calculations in 1989. The rod-shaped lattices indicate organic molecules linked by copper ions, and the ball-shapes represent acetone molecules incorporated in the spaces. The structure was published in 1992.

A Relaxed Moment Brings Inspiration

The turning point came in 1989. Together with two Kindai University students, Kitagawa visited Kyoto University, where a large computer for X-ray structure analysis of single crystals was made available. They input the X-ray diffraction data obtained for a coordination polymer crystal and then waited for modeling and simulating the structure. "Many researchers were using the computer at the same time, so the process took more than an hour until we get our result. If we had been part of Kyoto University, we could have gone back to our own lab and done some other work, but as visitors we had nowhere in particular to go. We just had time on our hands. Eventually we started looking at some preliminary results to try and predict the structure, and one of the students said, 'Hey, there are holes in it.'" When Kitagawa saw the honeycomb-like network structure, he noticed there are regular array of cavities. Kitagawa instantly made up his mind.

"Most coordination chemists were looking only at the frameworks themselves of the polymers, and paid no attention to the interstices. But I thought those totally empty spaces were something interesting."



Porous coordination polymer diagrams drawn by Kitagawa for his 1997 paper.
Left: A unit of porous material. The blue parts are metal ions, bound by organic molecules. Through polymerization, the material creates the porous structure shown below. Right: Simplified drawing of the structure of the molecular model. The green and orange sections represent different layers with essentially the same tongue-and-groove structure.

That was the moment when his research focus made a crucial shift.

Nonetheless, it would be some time before he arrived at the idea of "porous materials." Solvent molecules within the pores play an important role in the stability of the crystal, and their removal would cause the framework to collapse. "I wasn't thinking at first about utilizing the pores." After two years of trial and error, on the idea that these molecules could be removed and leave a non-collapsing framework, the first porous coordination polymer was completed. Allowing gas to flow freely through the countless minute empty spaces, groundbreaking findings emerged that extended the applications of the porous structure. Yet when first published in 1997, the reception to this finding was cool. "At the time, everyone thought that 'organic matter is soft, so a framework of porous material is not usable.' Our work was seen as an adsorption experiment mistake and hardly believed by other scientists. It was even denounced as a lie…" Only when enough other researchers had similar findings, was it accepted that a solid pore structure can be made using organic matter. Suddenly, porous materials research became a fiercely competitive field.

Training His Students to Nurture Intuition

"When told 'There are holes in it,' I might have simply thought, 'It is not an electron conducting framework, so it's useless,' were I the type to go strictly by the rules. From this, I may have abandoned the idea. But I had a feeling that the vacant 'space' was something interesting, and instead I followed the path of my intuition," says Kitagawa.

The secrets to success, Kitagawa constantly tells his students, are luck, patience, and persistence. "Luck is not something of chance, like in a lottery. Rather it is something encountered after a person unknowingly moves toward it. The famous dictum of the bacteriologist Louis Pasteur, "Chance favors the prepared mind," reflects this. With hard work, a foundation is built that can respond to favorable chance. Patience means not reacting quickly. A sharp person may understand phenomena quickly and immediately move forward. But I believe the opportunity to generate new fields of science comes to slower types, who pause to skeptically review the situation. Persistence is, of course, the sheer perseverance to keep believing without giving up." When a student of Kitagawa reaches the milestone of becoming a professor, he presents them with a traditional ceramic owl – a symbol of wisdom – with these three words hand-written on it by Kitagawa himself.

A ceramic owl is presented to each student when they become a professor, encouraging them to take a wide, bird's-eye view of their field. A symbol of wisdom, the extensive range of the owl's neck rotation allows it to see the entire landscape.

Celebrating his 60th birthday with students.

Endowing Materials with Abilities Beyond Natural Organisms

When iCeMS was founded in 2007, Kitagawa was named the deputy director. There are two founding principles of the institute. "One is to describe cellular processes in terms of chemistry and create materials to control them, an aim that contributes to the medical treatment of illness or dysfunction. The other is to create functional materials inspired by cellular processes." One of Kitagawa's motivations is to create materials that can accomplish things that natural organisms cannot. For example, a natural cell membrane can transmit a substance both from the more concentrated side to the less concentrated side and also vice versa, yet it will not transmit all substances. "The mechanisms of life are quite well designed, but they do not function beyond their given roles. Human-designed materials may achieve additional functions."

2017 marked twenty years since the porous coordination polymers were developed. "Our bodies are made up of various proteins that are formed from just 20 different amino acids. The body assemblage is achieved by the widely divergent combinations. Similarly, porous coordination polymers can be synthesized from the combinations of components enormously more numerous than proteins. Even the most powerful computer programs can't compute them all for exact structures and functions. This is exactly why we find rich veins away from the main road and why we need the patience, from 'luck, patience, persistence.' The fun of materials science is that so much may lie buried beneath our feet."

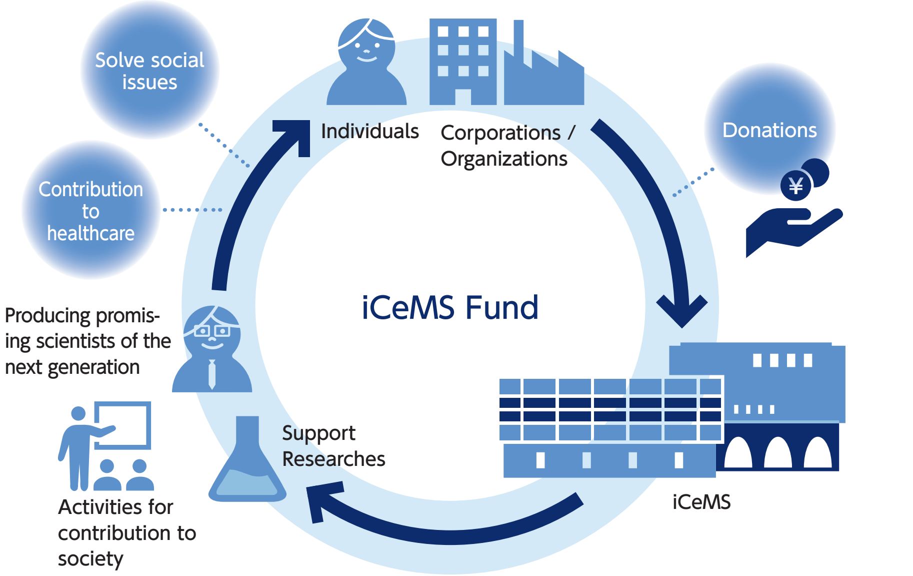
iCeMS Fund — Help us grow

iCeMS is the only research institute in Japan that combines chemistry and cell biology to develop new research areas. With this perspective, we aim to create new functional materials and chemical substances, such as "gas medicines" that utilize carbon monoxide and nitric oxide, among others. Our revolutionary work also addresses key issues, such as global warming, pollution, fossil fuels dependency, and the availability of clean drinking water.

Research at iCeMS is called "Pure research". Although it is difficult to see the results, knowledge gained from pure research is indispensable for the development of applied research that can contribute to society. To reach this goal the Center for iPS cell Research and Application (CiRA) was born, developing clinical research from pure research on iCeMS stem cells. It takes a long time before pure research is actually used in society. Therefore, it is necessary to develop a stable system of research for the long term.

iCeMS has grown considerably in the ten years since the 2007 MEXT "World Premier International Research Center Initiative (WPI)". The program's support has ended, but young researchers, who developed with iCeMS in the ten years since its founding, are experiencing emerging success in their fields. By providing a place for them in the future, we hope to further disseminate high impact research results to the world and further grow as research laboratories.

In order to realize such growth, it is, of course, important to acquire outside research funds, but it is also urgently necessary to build a stable fiscal foundation to ensure the continuity of high level training. We appreciate your understanding about the activities and spirit of iCeMS, and we thank you for your continued support through the iCeMS Fund.



Donors

iCeMS would like to sincerely thank all those who have given their support.

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Kyoto University Fund webpage

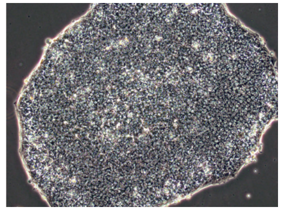
http://www.kikin.kyoto-u.ac.jp/contribution/icems/

iCeMS in brief

• Research Highlights • For more information (www.icems.kyoto-u.ac.jp)

Culturing cheaper human pluripotent stem cells

The research group led by Kouichi Hasegawa has developed a new medium and a new method for culturing hPSCs. The new medium is made with chemical compounds in stead of expensive growth factors, and that makes this medium five to ten times cheaper than any currently available hPSC culture medium. This is expected to reduce the cost of drug discovery and medical application, accelerating research.



A human embryonic stem cell colony cultured in the newly developed medium.

Realizing the ultimate structure of organic solar cells

The research group led by Susumu Kitagawa and the research group of the Ecole Normale Superieure in France has, by using a porous material, created a structure in which two different molecules are arranged in a regular and alternate pattern. It is regarded as the ultimate ideal structure for an organic solar cell material with a charge lifetime of 1,000.

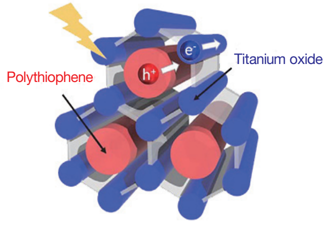
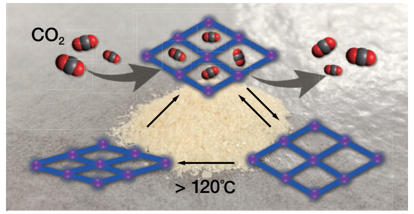


Image of the created structure (donor-acceptor alternate array structure)

A shape to remember

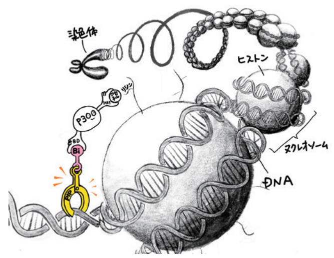
Susumu Kitagawa and colleagues have demonstrated a shape-memory effect in a flexible metal organic material, developing new carbon-dioxide-adsorbing crystals. This new porous material absorbs CO_2, and retains its shape even after CO_2 molecules are removed. Their work could provide the basis for designing more shape-memory porous materials.



The pores in the crystal remain open after the release of CO_2, but they can be collapsed easily with heat.

Programming synthetic molecular codes to turn genes 'ON'

Ganesh Pandian Namasivayam and colleagues fabricated a molecular code called "Bi-PIP" that mimics a key process that turns on genes in the body. The code targets histones, the proteins that are responsible for packaging DNA so that it fits inside a cell's nucleus. When histones undergo a chemical process called acetylation, an acetyl group is added to part of their structure. This loosens the DNA's attachment to the proteins, which leads to gene activation. This process could help lead to future gene-based therapies for a wide array of diseases.



Bi-PIP was successful in emulating the natural histone acetylation process and led to the activation of a specific gene associated with the central nervous system inside living cells. (Drawn by Izumi Mindy Takamiya)

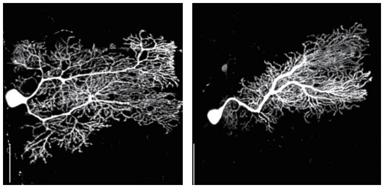
Technique reveals complex protein movements in the cell membrane

The research group led by visiting professor Akihiro Kusumi and associated professor Takahiro Fujiwara has developed an imaging method for live cells, in collaboration with the Okinawa Institute of Science and Technology Graduate University (OIST). Their method improves the observation time of fluorescent molecules by forty-fold. With the increased time window of observation, the researchers were able to study how molecules work in the cell far more directly and clearly.

The single-molecule imaging station in OIST.

Building trees: the protein controlling nerve cell branching

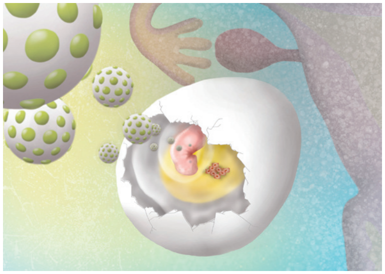
Kengaku and her team found that inhibiting the expression of protein MTSS1 in Purkinje cells of baby mice led to incomplete dendrite growth, indicating that MTSS1 is an important regulator of their development. Researching the role of MTSS1 in the development of branching dendrites in Purkinje cells can aid in the development of therapies for neurodegenerative disease, damaged brains and cancer.



Microscope image of cerebellar Purkinje cells from mice. Purkinje cells (right) lacking the MTSS1 gene have a reduced number of protrusions compared to Purkinje cells (left) of normal wild type mice.

A major step towards individualized cancer therapy

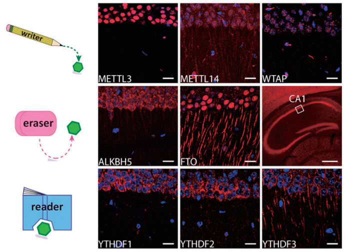
Fuyuhiko Tamanoi and colleagues have developed a "chicken egg tumor model", in which cultured ovarian cancer cells are transplanted on top of the membrane that surrounds a 10-day-old chicken embryo. An ovarian tumor forms on top of the membrane within three days of transplantation. They also developed a new type of biodegradable silica nanoparticle called 'biodegradable PMO', which can prevent anti-cancer drug side effects.



The chicken egg model drawn by Izumi Mindy Takamiya.

Visualizing RNA activity within the brain tissues of live mice for development of novel drugs

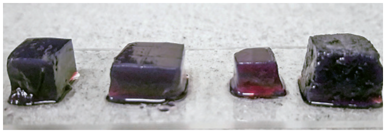
A group led by Dan Ohtan Wang found that a molecule, called m^{6}A, makes modifications at brain nerve junctions that are essential for proper signal transmission. This could help further understanding of neurodevelopmental and neuropsychiatric disorders, including autism.



In vivo proteins in mice controlled by m^{6}A (upper row: writer, middle row: eraser, lower row: reader) exist in the dendrites of hippocampal neurons.

Controlling the manufacture of stable aerogels

Shuhei Furukawa with colleagues have developed a new approach to control the fabrication of soft, porous materials, overcoming a primary challenge in materials science. The developed materials have a stable structure, despite their tiny cavities, and have a wide variety of potential applications. Building insulation, energy storage devices, aerospace technologies, and even environmental clean-ups can all benefit from incorporating light and flexible materials.



The newly developed porous gel.

• What's new? •

For more information (www.icems.kyoto-u.ac.jp)

- iCeMS ties MoU with R&D Center for Membrane Technology, Chung Yuan University (3/16)
- iCeMS-CiMPhy holds kick-off symposium (4/11)
- iCeMS collaborates with ShanghaiTech University (7/19)
- iCeMS participates in the SSH research presentation (8/8-9)
- Students from four high schools participate in iCeMS Caravan visit (8/8)
- iCeMS establishes "Smart Materials Research Center" in Thai (8/22)
- iCeMS holds its 24th International Symposium (9/3)
- iCeMS ties MoU with AO Research Institute Davos of Switzerland (9/3)

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