Outline of Selected Project

Host institution	Hiroshima University
Center name	International Institute for Sustainability with Knotted Chiral Meta Matter ($SKCM^2$)
Head of host institution	Mitsuo Ochi
Prospective Center director	Ivan I. Smalyukh

＜Project Summary＞

The need of securing sustainable, prosperous future strongly motivates us to conduct highly fundamental research that also has the potential of helping to address challenging global problems, like the growing energy demand and climate change. In our interdisciplinary approach, we develop knotted structures of physical fields (like the magnetic field or molecular alignment field) that have properties of particles, resembling atoms, molecules and other building blocks of the natural world. To gain the ability of designing such artificial atoms and molecules at will, we fuse the knowledge in math, physics, chemistry, biology & material science, across space & time scales. Synergistic with Feynman's words "What I cannot create, I do not understand", we deepen understanding of physical phenomena by re-creating their artificial analogs, thus gaining insights into the behavior of physical systems that are relatively inaccessible to experiments, like Early Universe cosmology. This our approach also allows for making new forms of artificial matter by design, with physical properties not encountered in the naturally occurring systems, allowing us to achieve highly desirable material properties. Knotted structures of fields in magnets can be used for data storage and the ones in liquid crystals can enable new types of displays. On the other hand, porous crystals made from knotted molecules can enable new breeds of building materials with thermal superinsulation properties, helping to save a fraction of about 40% of all energy generated globally that currently goes into heating and cooling of energy-inefficient buildings to maintain comfortable indoor environment. Our basic research is poised to foster technological innovation to address some of the biggest global challenges, like the need to reduce the growing energy demand and mitigate climate change caused by generating this energy.

<Remarks>

1. The project is novel and interdisciplinary, involving mathematics and material science, as it looks for and designs materials that have interesting topological and symmetry properties. Though somewhat converse to the usual approach of finding interesting properties in materials existing in nature, knotted chiral matter has potential for substantial development given the

excellent PIs from diverse disciplines gathered worldwide at the center.

2. The prospective center director Ivan I. SMALYUKH is an excellent scientist with visions and successes in the field of chiral liquid crystals. He is a strong leader with management experience and is able to motivate students and transfer his enthusiasm to the public.

3. The overseas training and exposure opportunities for both postdocs and administrative staffs as well as the center's unique degree programs are innovative elements at the system level.

4. The proposed center receives very strong support and commitment from the president of Hiroshima University, who views the center as being a spearhead for reforming the University in terms of internationalization and diversity.

Hiroshima University

International Institute for Sustainability with Knotted Chiral Meta Matter (SKCM²)

Center Director
Ivan I. Smalyukh

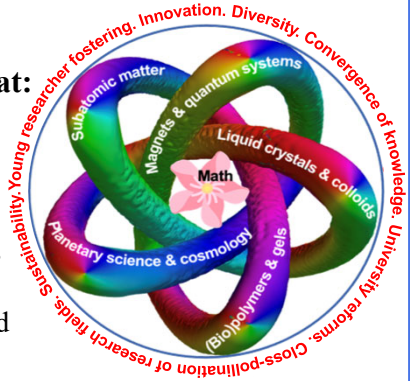
Professor Smalyukh is a World leader in material research and a recipient of many awards, including a presidential career award from the US White House. Within this project, he and the Center aspire to create new types of artificial materials by design, with physical properties not encountered in natural systems. This approach will enable highly desirable material properties needed to help address challenging global problems, like the growing energy demand and climate change.

Mission

We will develop artificial analogs of molecules, atoms and even smaller building blocks of nature to gain deeper understanding of the World around us. We will introduce designable materials with highly desirable properties not encountered in nature, as well as create foundations for technological innovation to solve global problems & enable sustainable future. While pursuing this research, we will create a testbed for research-based graduate education reforms in Japan & beyond, connecting young talent globally and inter-linking natural & social sciences for sustainability.

Identities

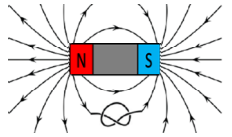
SKCM² is the only institute globally that:



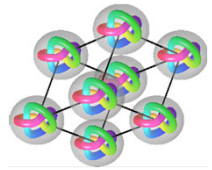
- develops knots in fields as designable building blocks of artificial matter, thus introducing a new paradigm of "knotted chiral meta matter"
- creates materials from such artificial designable particles to exhibit highly unusual & technologically useful properties, overcoming nature's limitations
- cross-pollinates mathematical knot theory & chirality knowledge across disciplines & scales

Research

Just like one can make a knot in a string, physical field lines (like the force field lines created by a magnet) can be knotted too. These knots then exhibit properties of particles, which are artificial analogs of atoms. We can create them at will in materials like magnets & liquid crystals with the help of chirality, a property of objects with mirror images not overlapping each other, like our right and left hands. We seek to establish a research paradigm of "knotted chiral meta matter," with such knots in physical fields as its building blocks. We will probe fundamental laws of nature at scales from its smallest building blocks to the entire Universe through recreating natural phenomena in experimentally accessible systems, like the liquid crystals used in displays. To accomplish this, we will integrate knowledge in pure & applied math with that in physics, planetary science, cosmology, biology, material science & engineering. By knotting & knitting physical fields and molecules, much like in the Mizuhiki artforms, we will help reveal mysteries of nature & enable new physical behavior & desirable properties that overcome its limitations. We will create crystals of knots in fields and other artificial analogs of natural matter, making new materials by design. For example, we will enable thermal superinsulation needed to save energy wasted for heating and cooling buildings, which consume 40% of all energy generated globally. Saving this energy by adopting our materials would help reduce the global energy demand and mitigate climate change.



force field lines



Knotted chiral meta matter

Superinsulation

Collaborations

SKCM² is a partnership of Hiroshima Univ. with RIKEN, Univ. of Tokyo & Tokyo Tech in Japan & MIT, CU-Boulder & Georgia Tech in the USA, Utrecht Univ. in the Netherlands, Cambridge Univ. in the UK, Max Plank Institute in Germany, Univ. of Wroclaw in Poland & Academia Sinica in Taiwan.