Joint Studies Programs

As one of the important functions of an inter-university research institute, IMS facilitates joint studies programs for which funds are available to cover the costs of research expenses as well as the travel and accommodation expenses of individuals. Proposals from domestic scientists are reviewed and selected by an interuniversity committee.

(1) Special Projects

(a) Establishing a Unified Picture of Multiscale Quantum Functions in Chiral Materials

KISHNE, Jun-ichiro (*Open Univ.*)
TOGAWA, Yoshihiko (*Osaka Metropolitan Univ.*)
SATO, Takuya (*Tokyo Inst. Tech.*)
KUSUNOSE, Hiroaki (*Meiji Univ.*)
KATO, Yusuke (*Univ. Tokyo*)
YAMAMOTO, Hiroshi (*IMS*)

The term “chirality” refers to forms that are mirror images of each other but cannot be superimposed, like right and left hands. As a term describing molecular shapes, it has become widely recognized across various branches of molecular science. A noteworthy point is the subtle connection between macroscopic hands and microscopic molecules, both referred to by the same term, “chirality.” This connection raises an important question: How can the macroscopic classical world and the microscopic quantum world be linked? One of the key goals for material science researchers is to explore material functions on multiple scales and bridge these two realms. The analogy between “molecules and hands” illustrates the multiscale nature of chirality. Under this common keyword “chirality,” vast research fields are expanding, spanning physics, chemistry, life sciences, and even space science. Chirality serves as a unifying concept across these disciplines.

The reason we focus on chirality is that while it may appear to be a geometric and static concept, chirality actually connects quantum degrees of freedom, such as charge, orbit, spin, and lattice vibrations, leading to a wealth of material functions. To use a familiar analogy, when ascending or descending a spiral staircase, one inevitably rotates around the helical axis. In other words, translation and rotation are coupled. Applying this perspective to materials reveals that electrical and magnetic degrees of freedom are similarly coupled.

Recently, the field of “chiral material science,” which explores the structure and function of materials from this perspective, has emerged. Fields such as chiral magnetism, chiral plasmonics, chiral spintronics, chiral phononics, chiral optics, and chiral electronics are all emerging areas that are very active today. If you remove the prefix “chiral” from the names of these fields, you find they encompass nearly the entirety of physics and chemistry.

The goal of this research project was to bring together six researchers—three experimentalists and three theorists—who are fascinated by chirality, to investigate how microscopic quantum mechanical degrees of freedom, such as electron spin, orbit, and atomic vibrations, couple in chiral materials. Using techniques such as circularly polarized Raman spectroscopy and spin-polarized transport measurements, we have studied the chiral responses of a wide range of materials, including organic and inorganic compounds, conductors, semiconductors, dielectrics, bulk crystals, and thin films. These experimental investigations have been complemented by theoretical research.

Several significant achievements have emerged from this research. We successfully observed lattice vibrations (phonons) unique to chiral crystals using circularly polarized Raman scattering and identified the quantum numbers of phonons derived from chirality through Raman selection rules (Sato, Kishine, Togawa *et al.*, *Nat. Phys.* **19**, 35–39 (2023)). In addition, we discovered that applying a thermal gradient to quartz, a representative chiral inorganic crystal, induces a spin current, a previously unobserved phenomenon (Togawa *et al.*, *Phys. Rev. Lett.* **132**, 056302 (2024)). We also proposed a theoretical framework for defining chirality in quantum terms (Kusunose, Yamamoto, Kishine, *Israel J. Chem.* **62(11-12)**, e202200049 (2022); *Appl. Phys. Lett.* **124**, 260501 (2024)).

These studies, while seemingly diverse, all relate to elucidating the phenomenon where the spins of electrons passing through chiral molecules or crystals exhibit huge spin polarization. This phenomenon, known as Chirality-Induced Spin Selectivity (CISS), was first discovered by Naaman’s group in Israel. CISS occurs on multiple scales, from DNA and peptides to inorganic crystals, and aligns electron spins without the need for a magnetic field, even at room temperature. This makes it a highly attractive phenomenon, and understanding its mechanism is a profoundly important scientific goal. All of the results from this project are critical steps towards unraveling the CISS mechanism.

To further advance this research, we have established the “Quantum Mechanical Research Initiative for Chiral Materials (QuaRC)” at the Institute for Molecular Science (IMS) (https://www.quarc-ims.com/). Leveraging IMS as a joint-use facility, we aim to develop this initiative into a consortium that promotes chirality research from both the physical and chemical perspectives.

Finally, we stress that brainstorming and refining ideas often become a lengthy process, much like an endurance race in front of the whiteboard, requiring in-depth, face-to-face interaction. A key achievement during this research period was the regular in-person meetings in Okazaki, where the six team members gathered multiple times for productive discussions.

(2) Research Symposia

(From Oct. 2023 to Sep. 2024)

Dates	Theme	Chair
Oct. 2–4, 2023	Frontier of Soft X-Ray Spectroscopy for Chemical Processes in Solutions	**NAGASAKA, Masanari** **KERA, Satoshi**
Aug. 19–23, 2024	The 63rd Summer School in Molecular Science	**TANAKA, Ryoichi** **SUGIMOTO, Toshiki**

(3) Numbers of Joint Studies Programs

Categories		Oct. 2023–Mar. 2024		Apr. 2024–Sep. 2024		Total		
		Regular	ARIM	Regular	ARIM	Regular	ARIM	Sum
Special Projects		1		0		1		1
Research Symposia		1		0		1		1
Research Symposia for Young Researchers		0		1		1		1
Cooperative Research		16	28	18	26	34	54	88
Use of Facility	Instrument Center		98		73		171	171
	Equipment Development Center	0	5	0	6	0	11	11
	UVSOR	87	2	118	1	205	3	208
Use of Facility Program of the Computer Center						302*		302*

* from April 2023 to March 2024