Report on MERIT Domestic Internship

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MERIT 9th term Student

Period

September 6–October 6, October 8–October 15, 2021

Host institutes / Person in charge

- Institute for Molecular Science (IMS) / Prof. Hiroshi M. Yamamoto
- Yukawa Institute for Theoretical Physics (YITP) / Prof. Masatoshi Sato

Overview

I worked on the following tasks at each of the two research institutes above:
(1) Discussion on spin transport properties peculiar to chiral materials
(2) Generalization of the theory of spin current associated with Zener tunneling to three-dimensional systems

As the task (1), I had discussions with the Yamamoto Group at IMS, one of the research centers in Japan in the field of the spin transport in chiral materials, during the internship from Sep. 6 to Sep. 15. At first, we have planned on-site discussion, but changed to talk online as a prevention measure against COVID-19.

After that, for a period of a month, I studied on the theme (2) through discussions with the people in condensed matter physics groups in the YITP and Graduate school of Science, Kyoto University. I stayed on-site in this time, thanks to a visiting program of 2021 hosted by YITP.

Research topic

At IMS (online)

There are unique spin transport properties allowed by symmetry in chiral materials that cannot be superimposed onto its mirror image. For example, the chiral-induced spin selectivity (CISS) effect, which was found experimentally, generates a spin polarization parallel to the direction of electron flow even in nonmagnetic materials.

Recently, the CISS effect is reported in the linear regime for some chiral crystals. However, it remains unclear what is the microscopic origin of (i) this response much larger than that of the current-induced magnetization, which we naïvely assume to be the CISS effect, and (ii) strange long-range spin transport over micrometers.

In the discussion with the Yamamoto Group, I attempted to formulate the phenomenological model of (i) and (ii). I took precise advice from Prof. Yamamoto, Assistant Prof. Hirobe, and Assistant Prof. Sato, which encouraged a reformulation of the presented model.

I also talked with Assistant Prof. Shitade in this institute. We discussed his theoretical proposal on the CISS effect and the theme (2), which is detailed below.

At YITP

A strong electric field applied to an insulator where dissipation can be almost neglected, results in a nonadiabatic transition of electron across the band gap, which is known as Zener tunneling. It is recently found that the amplitude of the tunneling probability is generally corrected by geometric nature of wavefunction. We can show that such correction yields the spin dependent tunneling even in the PT symmetric insulators where band dispersions are inevitably degenerate with opposite spins, and that nonzero spin current can be associated with the tunneling.

During my stay in YITP, I engaged in research to extend the result above, which holds for one-dimensional system where certain spin component is a good quantum number. I tried to generalize it for general two- or three-dimensional systems. Here, it is important to investigate the properties of shift vector, which is a geometric quantity constructed from Berry connections, reflecting the crystal symmetry.

For this research, I presented this topic and my results at the formal YITP seminar and discussed with Assistant Prof. Shiozaki, Prof. Yanase and Assistant Prof. Daido. One of their proposals that points out an analogy with the theory of shift current was so helpful to my research.

Impression

I have got acquainted with many researchers during my stay in YITP for a month. Since the state of emergency in Kyoto was lifted around that time, I had an impression that the people in the institute was very active in discussions and interactions, both face-to-face and online. They are all generous to visitors throughout the stay: The rooms and desks assigned were spacious and comfortable for research activities, and I could freely join in seminars and journal clubs held by the condensed matter physics group, which motivated me so much. In the evenings and on weekends, I was invited to climb Mt. Daimonji and Mt. Hiei, which now reminds me of this fulfilling stay in Kyoto.

As for IMS, we are planning to visit the campus in November thanks to a joint research program, which was at first planned for this internship but postponed. I am looking forward to this visit to IMS in this autumn.

Acknowledgement

It has been a fulfilling internship through which I have met many researchers. I am deeply grateful to Prof. Hiroshi M. Yamamoto and Prof. Masatoshi Sato for the acceptation of this internship and recommending me to apply for the joint research program at IMS and YITP, respectively. I wish to thank Assistant Prof. Daichi Hirobe, Assistant Prof. Takuro Sato, and Assistant Prof. Atsuo Shitade at IMS, Assistant Prof. Ken Shiozaki at YITP, and Prof. Youichi Yanase and Assistant Prof. Akito Daido at Graduate school of Science, Kyoto University, for constructive discussions on the subjects. I particularly appreciate Assistant Prof. Shiozaki for continuous supports and kind guides around YITP. In addition, I would like to express my gratitude to my supervisors Prof. Yusuke Kato and Prof. Eiji Saitoh for agreement with this internship program and introducing me to Prof. Yamamoto and Prof. Sato. Finally, I sincerely thank MERIT program and Ms. Asano in MERIT Office for providing this precious opportunity.