# MERIT report for long term overseas stay

Duration of stay : 2/6/2019 ~ 28/11/2019

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[Overview]
I stayed in University of Toronto from June 2nd to November 28th in order to conduct a collaborative research with Prof. Yong Baek Kim. In this report, I would like to give a short summary of the research project during my stay and daily life in Canada.

[Background]
When I started my PhD course, I wanted to work on the theory of quantum spin liquid (QSL) as a new research topic. After Kitaev proposed an exactly solvable model for QSL, the search for QSL phase became a central topic of condensed matter physics both theoretically and experimentally. There are three groups for theoretical condensed matter research at the University of Toronto, and they all work on the study of QSL as the main research topic. Thus, the students and postdocs are familiar with the physics of QSL. I thought this environment is very suitable for my purpose. My supervisor Prof. Ogata knows Prof. Yong Baek Kim well, so he recommended that I should visit Yong Baek Kim's group.

[Research topic]
During my stay, I worked on the theory of detecting "multipolar quantum spin liquid phases", which emerge when local multipolar moments interact with each other on a geometrically frustrated lattice. The rare-earth pyrochlore system is known as one such example. The complexity of the study of QSL phases stems from the difficulty of detecting them by conventional probes due to the lack of long-range order. On the other hand, seemingly disjointed phases of matter, multipolar ordered phases (MPOs) are known to be shy away from conventional proving techniques. Recently, a lattice-based probe is proposed as a novel tool for detecting MPOs in heavy fermion systems. Motivated by this success, we ask: could the experimentally reticent QSLs be exposed if they arise from interacting multipolar moments?
First of all, we categorized the rare-earth pyrochlore system into the following three cases depending on the symmetry of the ground state doublet; (i) Kramers case, (ii) non-Kramers case, (iii) dipolar-octupolar case. Among these cases, higher-rank multipoles are active for (ii) and (iii). Here, we focused on (ii) because this situation is actively studied.
Next, using a symmetry-based technique, we derived the expressions for multipole-lattice

interactions. Besides, considering the coupling between the external magnetic field and multipolar moments, we obtained the formulae for the magnetic field dependence of the magnetostriction.

Finally, using the obtained formulae and the analysis of the effective spin model, we calculated the magnetic field dependence of magnetostriction for non-Kramers pyrochlore systems. As a result, we found that the unique behaviours are realized only for the QSL phase. This result shows the usefulness of magnetostriction as a novel probe for QSLs. We have already published the paper about these achievements to the preprint server arXiv.

[Daily life in Canada]

Though Toronto is the biggest city in Canada, it is a more quiet city compared to Tokyo, and thus I could spend a calm life. Also, because of racial diversity in Canada, I could experience various cultures. For instance, we can try Afghan, Persian, and Ethiopian restaurant in Toronto, which we can hardly find in Japan. As for the weather in Toronto, the summer is very comfortable. However, the beginning of winter is much earlier than in Japan, and I experienced -14 degree in November.

Yong Baek Kim's group is smaller than our group. Instead, communication with the students in other groups is active, so the research environment is well organized. During my stay, in addition to the discussion of my work, I enjoyed table tennis or skating with the group members. I am really looking forward to seeing them again in various conferences in the future.

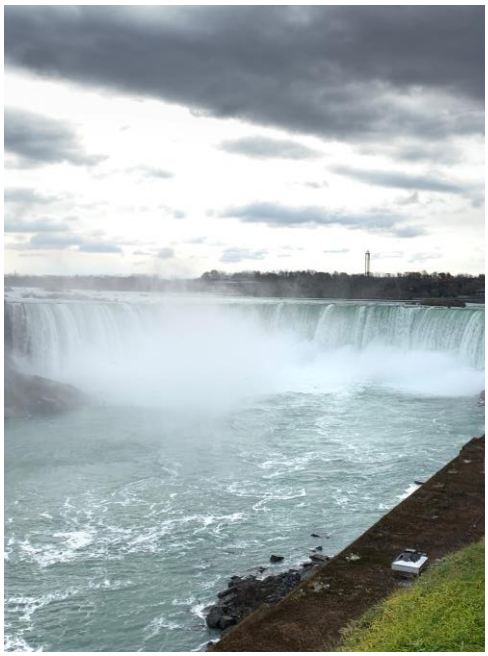

Fig. 1. Niagara Falls, one of the three major waterfalls in the world.

In holidays, I was able to visit various sightseeing places. Especially, I was moved by the beautiful scenery of Niagara Falls, which is located in the place one hour and a half away by bus from Toronto. I am satisfied that I was able to visit almost all the places I wanted to visit during my six months stay.

[Acknowledgement]

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