Report of the RCNP Collaboration Research Network (RCNP-COREnet)

COREnet006 PI: HAGINO Kouichi

1	Title of research		Quantum dynamics for superheavy elements
2	List of Participants (Name and affiliation)		Kouichi Hagino (Kyoto Univ.),Masaaki Tokieda (Tohoku Univ.),
			Kouhei Washiyama (Kyushu Univ.), Kazuyuki Ogata (RCNP)
			Tatsushi Shima (RCNP), Yasuhisa Abe (RCNP)
3	Period of research		From September, 2019 to March, 2021
4	Main location of collaboration implementation		RCNP
5	Publication list (Please include DOI if available)	Articles	M. Tokieda and K. Hagino, "A new approach for open quantum systems based on a phonon number representation of a harmonic oscillator bath", Ann. of Phys. 412 (2020) 168005. doi.org/10.1016/j.aop.2019.168005
			M. Tokieda and K. Hagino, "Time-dependent approaches to open quantum systems", Front. In Phys. 8 (2020) 8. doi.org/10.3389/fphy.2020.00008
			Y. Abe, D. Boilley, Q. Hourdille, and C. Shen, "A dynamical study of fusion hindrance with the Nakajima-Zwanzig projection method", Prog. Theo. Exp. Phys. 2021 (2021) 021D01. doi.org/10.1093/ptep/ptab005
		Talks	K. Hagino, "Towards a microscopic understanding of compound nucleus reactions" (Online workshop on nuclear reactions as an evolution of time hierarchy of quantum systems, online, October 8, 2020).
			K. Hagino, "Recent progress and future perspectives of fusion and fission dynamics: from nuclear astrophysics to superheavy nuclei" (A3F program joint annual meeting, online, November 18, 2020).
			K. Hagino, "Role of quantum mechanics in a diffusion process for superheavy elements" (The virtual superheavy elements seminars, online, December 8, 2020).
			K. Hagino, "Quantum many-body dynamics in nuclear reactions" (KEK joint colloquium, online, March 30, 2021).
			M. Tokieda, "Effects of energy dissipation on fusion reactions around the Coulomb barrier" (Online workshop on nuclear reactions as an evolution of time hierarchy of quantum systems, online, October 8, 2020).
			M. Tokieda, "Effects of energy dissipation on fusion reactions around the Coulomb barrier" (The 76th JPS annual meeting, online, March 15, 2021).
			K. Ogata, "Spatial decoherence and quantum-classical transition in nuclear reactions" (Online workshop on nuclear reactions as an evolution of time hierarchy of quantum systems, online, October 8, 2020).
			T. Shima, "Quantum correlation in multi-step nuclear reactions" (Online workshop on nuclear reactions as an evolution of time hierarchy of quantum systems, online, October 8, 2020).
			T. Shima, "Quantum multi-step processes in neutron optics" (The 76th JPS annual meeting, online, March 15, 2021).
		Theses	M. Tokieda, "Studies of open quantum systems with applications to dissipative barrier transmission in heavy-ion fusion reactions", March 2021, Tohoku University.
6	Description of the results and outputs		Because of the covid19 pandemic, we did not have a discussion meeting this year with the whole members. Instead, we had continued discussions within two subgroups. Hagino, Tokieda, Washiyama, and Abe had discussions on the role of quantum effects on heavy-ion fusion reactions. This has resulted in a development of a novel approach for open quantum systems, with which a quantum mechanical Hamiltonian with couplings to environment can be solved exactly for a short term evolution. If one applies this method to the well known Caldeira-Leggett Hamiltonian, this is equivalence to a quantum Langevin method, since the classical Langevin equation can be derived from the Caldeira-Leggett Hamiltonian. Tokieda and Hagino applied this method to the 16O+208Pb fusion reaction and pointed out that the dissipation may play an important role already in such a relatively light system. Washiyama has been trying to apply a similar method to heavy-ion fusion reactions for superheavy elements in order to clarify the quantum effects on evaporation residue cross sections at low energies. In connection to fusion for superheavy elements, another important outcome of the present CoreNet project is that Abe developed a new method for heavy-ion fusion reactions based on the Nakajima-Zwanzig projection operator method for non-equilibrium statistical mechanics. This method was shown to provide a clear picture of the injection point for an initial condition of the Langevin equation. The other subgroup consists of Hagino, Ogata, and Shima. This group has continuously discussed the dynamics of decoherence in nuclear reactions, from a novel point of view of an evolution of time hierarchy of quantum systems. In this point of view, direct reactions, pre-equilibrium reactions, and compound nucleus formation reactions are regarded as different time hierarchies, and the differences observed in these reactions can be uniformly understood in terms of a temporal evolution of quantum systems. Based on this idea, Ogata applied the semi-classical distorted wave model to a one dimensional system and clarified how the spatial decoherence is realized as a consequence of multistep processes. As a part of the present CoreNet project, Ogata, Hagino, and Shima organized an online workshop on nuclear reactions as an evolution of time hierarchy of quantum systems, which was held on October 8, 2020. The workshop was attended by about 50 participants, with many lively discussions during the workshop. Ogata, Hagino, and Shima also organized a similar symposium in the 76th JPS annual meeting. With the success of these workshops, an importance of the direction of physics which we have been discussing in the present CoreNet project was clearly demonstrated.