RIBF ULIC Symposium/mini-WS Report

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Date: Sep. 7, 2016

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Title	[RIBF-ULIC-miniWS035] Towards theoretical understanding of production reactions of superheavy elements
Date	August 31, 2016
Place	RIKEN Nishina Center RIBF Building
Language	[ ] English [✓] Japanese
HP address	http://indico2.riken.jp/indico/conferenceDisplay.py?confId=2354
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Financial support from ULIC (Users Office Use Only)	Total : 94,640 JPY [Breakdown] Travel Expenses Katsuhisa Nishio: 8,140 yen Jin Nakagawa : 28,160 yen Yoshihiro Arimoto: 28,160 yen Shoya Tanaka : 8,140 yen Koichi Hagio : 22,040 yen
Co-hosting / any financial support from other organization(s)	RIKEN Nishina Center (Uesaka-lab.)

Summary of discussions and its (expected) results:

In this mini-WS, several theoretical challenges for heavy-ion fusion reactions relevant to superheavy nuclei were intensively discussed. In particular, the discussions were made from the following two view points: (i) how to improve theoretical modellings in order to make an accurate and reliable prediction for Z=119 and 120 production reactions with ^{248}Cm target, for which the RIKEN-GARIS team plans to measure, and (ii) how to extend the current theoretical frameworks in order to handle fusion of neutron-rich nuclei, which is essential to reach the island of stability in future. The following conclusions were achieved:

1. For the approaching phase before two colliding nuclei touch with each other, the fusion dynamics with deformed stable nuclei have been more or less well understood with the coupled-channels approach. However, for neutron-rich beams, one needs to take into account the effect of multi-nucleon transfer processes, which has yet to be developed.
2. For the evolution phase of a mono-nucleus configuration towards a compound nucleus, one needs to extend the current Langevin approach so that the deformation of each fragment can be treated separately. This is important especially for the ^{50}Ti, ^{51}V, and ^{54}Cr induced fusion reactions for a production of Z=118-120 superheavy elements, for which the effect of dynamical deformation of the projectile nucleus is expected much larger than in the ^{48}Ca induced reactions. For this process, since the probability of the compound nucleus formation, P_{CN}, cannot be reached experimentally, it is important for a theoretical modelling to reproduce other quantities, such as the

total-kinetic-energy (TKE) distribution as well as the fragment mass distribution for quasi-fission process, in order to make a reliable prediction for P_{CN}.

3. For this evolution phase, the current approach needs to be extended in order to describe fusion of neutron-rich nuclei, especially to handle neutron emissions during the time evolution and a change in a potential energy surface as a consequence of the neutron evaporation. This has yet to be developed.
4. For the statistical decay of a compound nucleus, the theoretical method (that is, the statistical model) is well established, but there are so many parameters in it and it is thus important to perform error analyses. The level density parameters as well as the fission barrier height are main sources of theoretical uncertainties.
5. In order to improve the theoretical models, several experimental data can be helpful. In addition to capture and evaporation residue cross sections, these include quasi-elastic barrier distributions (for the approaching phase) and various properties of quasi-fission, such as the fragment mass distribution, the mass-angular-distribution, and the total kinetic energy (TKE) distribution. Such measurements will soon be carried out at RIKEN and JAEA.

During the free discussion session, several other important conclusions were also obtained:

(i) While it is very challenging to make a reliable prediction for the absolute value of cross sections, there may be a better chance to make a more accurate prediction for relative quantities, such as a difference in cross sections between two different systems.

(ii) For the ^{48}Ca induced reactions, the energy dependence of total evaporation residue cross sections is milder than that in cold fusion reactions. One needs to investigate whether this remains the case even for the ^{50}Ti, ^{51}V, and ^{54}Cr induced reactions.

(iii) It may be important to re-investigate the old idea of (HI,αxn) reaction, especially in connection with the Trojan horse method for nuclear astrophysical reactions.

All of these issues discussed during this workshop are important for further theoretical developments in the field of superheavy elements, and we have shared among the participants an idea that we need continuous efforts to tackle this difficult problem. For a short term activity, we have decided to carry out systematic studies with the current theoretical frameworks.

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