Optimum Incident Energy in the Search for New Elements

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ABSTRACT

In order to study the nucleus-nucleus interactions for syntheses of superheavy nuclei, we measured excitation functions for the quasielastic scattering of ^{48}Ca+^{208}Pb, ^{50}Ti+^{208}Pb, and ^{48}Ca+^{248}Cm using the gas-filled-type recoil ion separator GARIS. The quasielastic barrier distributions were successfully extracted for these systems, and compared with coupled-channels calculations. The results of the calculations indicate that vibrational and rotational excitations of the colliding nuclei, as well as neutron transfers before the contact, strongly affect the structure of the barrier distribution. For the double magic spherical target ^{208}Pb based reactions ^{48}Ca+^{208}Pb and ^{50}Ti+^{208}Pb, a local maximum of the barrier distribution occurred at the same energy as the peak of the 2n evaporation cross section of the system. On the other hand, the actinide deformed target ^{248}Cm based reaction ^{48}Ca+^{248}Cm; the 4n evaporation cross section of the system peaks at energies well above the maximum of the barrier distribution. This clearly suggests the evaporation residue cross sections are enhanced at energies that correspond to a compact collision geometry with the projectile impacting the side of the deformed target nucleus.

INTRODUCTION

New element search

The research group of RIKEN, Morita et al., synthesized 3 atoms of the element 113 (published in the *Journal of the Physical Society of Japan* [1,2,3]). For this work, the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Pure and Applied Physics (IUPAP) gave the naming right of the element 113 to the aforementioned group. The group proposed the name "Nihonium," and the name was accepted by IUPAC and IUPAP. The elements from 114 to 118 were synthesized by JINR (Joint Institute for Nuclear Research) group led by Yu. Ts. Oganessian.

Incident energy for superheavy nuclei syntheses

In superheavy nuclei syntheses such as new element searches, it is difficult to know the optimum incident energy. The lower side panels of Fig. 1 show the evaporation residue cross sections for syntheses of No (Z = 102), Rf (Z = 104) and Lv (Z = 116) isotopes. In the case of the No isotopes by using the reaction ^{48}Ca+^{208}Pb, optimum incident energy is $E_{c.m.}$ = 175.5 MeV. If we set the incident energy at $E_{c.m.}$ = 178.3 MeV, which is 1.6% higher than that of optimum incident energy, the cross section decreases about one third (35.2%). This means that it takes a period that is 2.8 times larger than in the optimum case to make 1 atom. In the case of experiments with very low cross sections such as Nihonium (1 atom / about 200 days), differences in the periods are a huge problem. Therefore, it is important to know the optimum incident energy for a new element search.

Previous works at RIKEN

The RIKEN group has measured the evaporation residues of the elements from 108 to 112 as a confirmation experiment of the GSI group led by S. Hofmann. From the results of the experiments, the RIKEN group noticed the systematics of the optimum incident energy and they determined the incident energy for synthesis element 113. However, in the case of the search for elements 119 and 120, we could not apply this method because we have to change the reactions from a "^{48}Ca + actinide target (the reactions were used for syntheses elements 114-118)" to a "^{50}Ti, ^{51}V, ^{54}Cr + actinide target". Therefore, the RIKEN group studied the optimum incident energy by understanding the reaction dynamics.

Fusion process for synthesizing superheavy nuclei

According to the fusion by diffusion model proposed by Swiatecki[4], we can distinguish the fusion process for synthesizing superheavy nuclei by the following 3 steps. (1)A projectile nucleus transits the Coulomb barrier by quantum tunneling. We define the cross section for this process as σ_{cap}. (2) After the previous process, the projectile and target nuclei make a compound nucleus. We define the probability of making a compound nucleus as P_{CN}. (3) In the evaporation process, the probability of some nuclei survival without fission is defined as P_{surv}. The evaporation residue cross section σ_{ER} was derived by the multiplication of these 3 values. By determination of the evaporation residue, we can confirm the syntheses of the superheavy nuclei. The study of fusion barrier distributions correspond to the determination of the reflection probability at the Coulomb barrier in the (1) process.

STUDY OF FUSION BARRIER DISTRIBUTIONS

We measured the excitation functions of quasielastic scattering cross sections σ_{QE} relative to the Rutherford cross

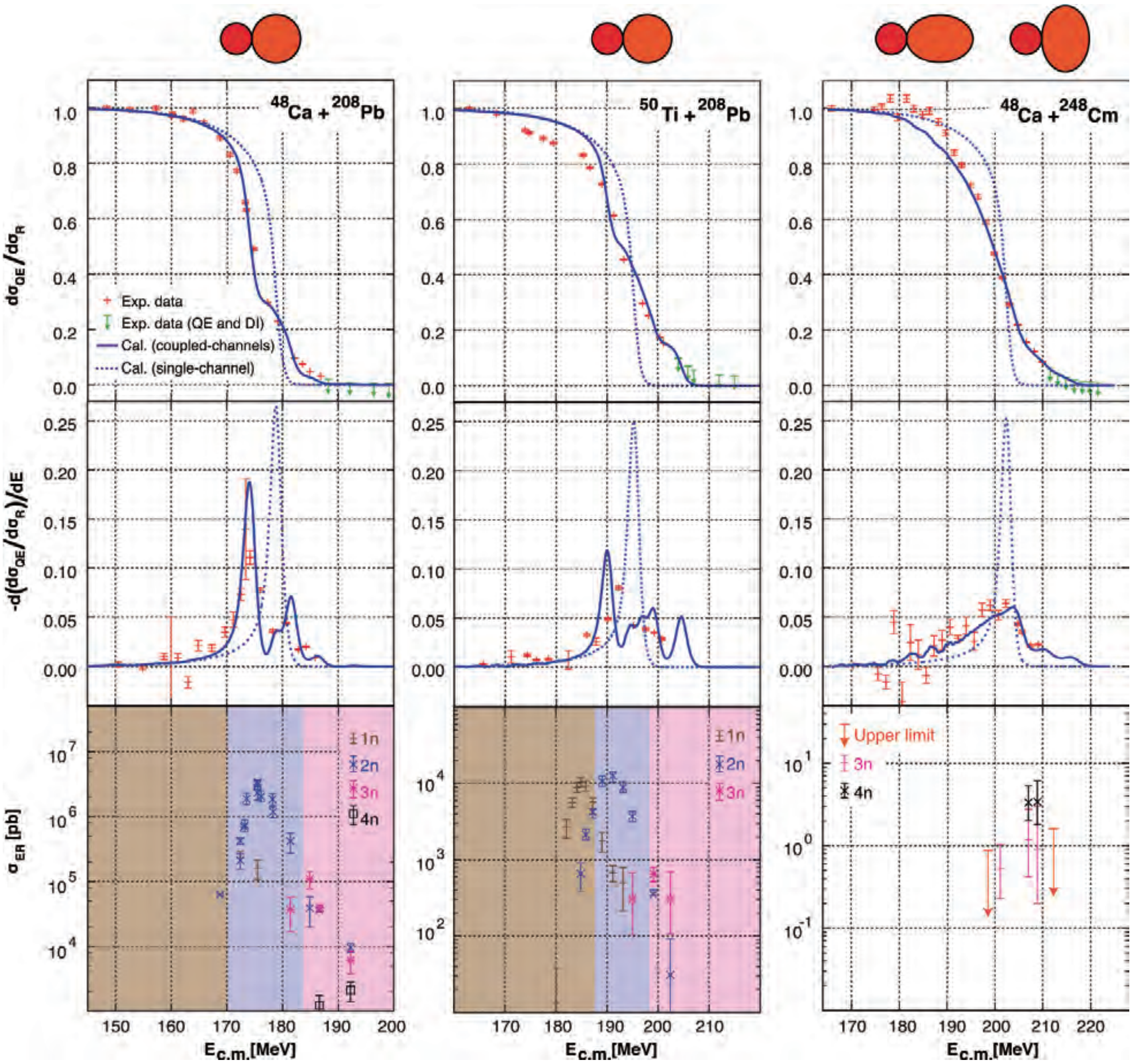

Fig. 1: Measured excitation function for the quasielastic scattering cross sections relative to the Rutherford cross section (top panels). Left, middle, and right panels are for the $^{48}Ca+^{208}Pb$, $^{50}Ti+^{208}Pb$, and $^{48}Ca+^{248}Cm$ systems, respectively. The corresponding quasielastic barrier distributions (middle panels) and the evaporation residue cross sections reported at different center-of-mass energies from the systems of No[Z = 102], Rf[Z = 104], and Lv[Z = 116] evaporation residues (lower panels) are shown.

sections σ_R; it corresponds to reflection probability at the Coulomb barrier (upper panels of the Fig. 1). The fusion barrier distributions were extracted by differentiation σ_{QE}/σ_R with respect to E (middle panels of the Fig. 1). From the comparison of the experimental barrier distributions and coupled-channels calculation results by CCFULL[5], the barrier distributions were strongly influenced by vibrational and rotational excitations of the colliding nuclei, as well as neutron transfers before the capture process. For the spherical nucleus target ^{208}Pb reactions ^{48}Ca+^{208}Pb and ^{50}Ti+^{208}Pb, the peaks of the barrier distributions were found to coincide with peaks of 2n evaporation residue cross sections. On the other hand, for the deformed nucleus target reaction ^{48}Ca+^{248}Cm, the peak of the evaporation residue cross section coincided with the above barrier region. This clearly suggests that the evaporation residue cross sections are enhanced at energies that correspond to a compact collision geometry with the projectile impacting the side of the deformed target nucleus. These results were published by *Journal of the Physical Society of Japan* [6].

WHAT'S NEXT?

The RIKEN group will try to synthesize new elements 119 and 120 by using the combinations of ^{50}Ti, ^{51}V, ^{54}Cr projectiles and ^{248}Cm, ^{250}Cf targets. Beyond the new element search, we may reach the "island of stability" which is made by double magic nuclei next to ^{208}Pb. We are further developing our studies to more deeply understand fusion dynamics. We hope that this knowledge will help us in synthesizing new elements.

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References

[1] K. Morita et al., J. Phys. Soc. Jpn. 73, 2593 (2004).
[2] K. Morita et al., J. Phys. Soc. Jpn. 76, 045001 (2007).
[3] K. Morita et al., J. Phys. Soc. Jpn. 81, 103201 (2012).
[4] W. J. Swiatecki et al., Acta. Phys. Pol. B 34, 2049 (2003).
[5] K. Hagino et al., Comput. Phys. Commun. 143, 123 (1999).
[6] T. Tanaka et al., J. Phys. Soc. Jpn. 87, 014201 (2018).

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