Nuclear Science and Transmutation Research Division
Superheavy Element Research Group
Superheavy Element Production Team

1. Abstract

The elements with atomic number $Z \geq 104$ are called as trans-actinide or superheavy elements (SHEs). Superheavy Element Production Team investigates synthesis mechanisms of SHEs, nuclear properties of SHE nuclei, and chemical properties of SHEs mainly in collaboration with Superheavy Element Devise Development Team and Nuclear Chemistry Research Team of RIKEN Nishina Center.

2. Major Research Subjects

(1) Search for new superheavy elements
(2) Decay spectroscopy of the heaviest nuclei
(3) Study of reaction mechanisms for production of the heaviest nuclei
(4) Study of chemical properties of the heaviest elements

3. Summary of Research Activity

(1) Search for new superheavy elements

In November, 2016, the 7th period of the periodic table was completed with the official approval of four new elements, nihonium (Nh, atomic number $Z = 113$), moscovium (Mc, $Z = 115$), tennessine (Ts, $Z = 117$), and oganesson (Og, $Z = 118$) by International Union of Pure and Applied Chemistry. We have started to search for new elements to expand the chart of the nuclides toward to the island of stability and the periodic table of the elements toward the 8th period. In January, 2020, RIKEN heavy-ion Linear ACcelerator (RILAC) was upgraded as Superconducting RIKEN heavy-ion Linear ACcelerator (SRILAC). We developed the new gas-filled recoil ion separator GARIS III on the beam line of SRILAC. In June and July, 2020, we conducted the commissioning of the SRILAC + GARIS III setup in the ^{169}Tm + ^{40}Ar, ^{208}Pb + ^{40}Ar, and ^{208}Pb + ^{51}V reactions. Then, we started to search for new element, element 119 in the ^{248}Cm + ^{51}V reaction in October, 2020.

(2) Decay spectroscopy of the heaviest nuclei

In collaboration with KEK, we developed a multi-refection time-of-fight mass spectrograph (MRTOF-MS) equipped with an α-TOF detector on the focal plane of GARIS-II at RRC for decay-correlated mass measurements of low-yield and short-lived SHE isotopes. By correlating measured time-of-flight signals with decay events, it can suppress background events and obtain accurate, high-precision mass and half-life values even in cases of very low event rates. The performance of the system was investigated using the Ra isotopes produced in the ^{159}Tb + ^{51}V reaction.

(3) Study of reaction mechanisms for production of the heaviest nuclei

SHE nuclei have been produced by complete fusion reactions of two heavy nuclei. However, the reaction mechanism of the fusion process is still not well understood both theoretically and experimentally. We measured excitation functions for the quasielastic scattering of the ^{248}Cm + ^{51}V reaction using GARIS III at SRILAC. The result can be utilized to estimate the optimal incident beam energy for production of isotopes of new element 119.

(4) Study of chemical properties of the heaviest elements

Chemical characterization of newly-discovered SHEs is an extremely interesting and challenging subject in modern nuclear and radiochemistry. In collaboration with Nuclear Chemistry Research Team of RIKEN Nishina Center, we are developing SHE production systems as well as rapid single-atom chemistry apparatuses for chemistry studies of SHEs. We installed a gas-jet transport system to the focal plane of GARIS at RILAC. This system is a promising approach for exploring new frontiers in SHE chemistry: the background radiations from unwanted products are strongly suppressed, the intense primary heavy-ion beam is absent in the gas-jet chamber, and hence the high gas-jet extraction yield is attained. Furthermore, the beam-free conditions make it possible to investigate new chemical systems. In 2020, we continued to develop an ultra-rapid gas-chromatograph apparatus at the focal plane of GARIS for the gas chemistry of SHEs. This apparatus consists of an RF carpet gas cell and a cryo-gas-chromatograph column with a Si detector array. For the aqueous chemistry, we developed a flow solvent extraction apparatus which consisted of a continuous dissolution apparatus Membrane DeGasser (MDG), a Flow Solvent Extractor (FSE), and a liquid scintillation detector for α/SF-spectrometry.

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List of Publications & Presentations

Publications

[Original Papers]

H. Haba, F. Fan, D. Kaji, Y. Kasamatsu, H. Kikunaga, Y. Komori, N. Kondo, H. Kudo, K. Morimoto, K. Morita, M. Murakami, K. Nishio, J. P. Omtvedt, K. Ooe, Z. Qin, D. Sato, N. Sato, T. K. Sato, Y. Shigekawa, A. Shinohara, M. Takeyama, T. Tanaka, A. Toyoshima, K. Tsukada, Y. Wakabayashi, Y. Wang, S. Wulff, S. Yamaki, S. Yano, Y. Yasuda, and T. Yokokita, "Production of ^{266}Bh in the ^{248}Cm(^{23}Na, 5n)^{266}Bh reaction and its decay properties," Phys. Rev. C **102**, 024625 (2020).

Y. Kasamatsu, K. Toyomura, H. Haba, T. Yokokita, Y. Shigekawa, A. Kino, Y. Yasuda, Y. Komori, J. Kanaya, M. Huang, M. Murakami, H. Kikunaga, E. Watanabe, T. Yoshimura, K. Morita, T. Mitsugashira, K. Takamiya, T. Ohtsuki, and A. Shinohara, "Co-precipitation behaviour of single atoms of rutherfordium in basic solutions," Nat. Chem. **13**, 226 (2021).

[Review Articles]

羽場宏光, 「元素周期表の新時代 119 番以降の新元素を求めて」, 現代化学 9 月号, No. 594, 43 (2020).

羽場宏光, 「スタニズラオ・カニッツァーロ」, 和光純薬時報, Vol. 88, No. 4, 28 (2020). Vol. 27, pp. 11–14 (2020).

[Proceedings]

T. Niwase, K. Fujita, Y. Yamano, K. Watanabe, D. Kaji, K. Morimoto, H. Haba, T. Hirano, S. Mitsuoka, and K. Morita, "Measurement of fusion barrier distribution in ^{51}V+^{208}Pb system," Proc. 13th Int. Conf. on Nucleus-Nucleus Collisions, JPS Conf. Proc. **32**, 010022 (2020).

Y. Sakemi, T. Aoki, R. Calabrese, H. Haba, K. Harada, T. Hayamizu, Y. Ichikawa, K. Jungmann, A. Kastberg, Y. Kotaka, Y. Matsuda, Y. Matsuo, H. Nagahama, K. Nakamura, M. Otsuka, N. Ozawa, K. Tanaka, A. Uchiyama, H. Ueno, and L. Willmann, "Fundamental physics with cold radioactive atoms," Proc. 14th Asia-Pacific Phys. Conf., AIP Conf. Proc. 2319, 080020 (2021).

Presentations

[International Conferences/Workshops]

H. Haba (invited), "Production and applications of radioisotopes at RIKEN RI beam factory—Search for new elements through diagnosis and therapy of cancer—," Symposium on Nuclear Data 2020, Wako, Japan, November 26–27, 2020.

Y. Komori (poster), H. Haba, M. Aikawa, M. Saito, S. Takács, and F. Ditrói, "Production cross sections of ^{175}Hf in the ^{nat}Lu(p,xn) and ^{nat}Lu(d,xn) reactions," Symposium on Nuclear Data 2020, Wako, Japan, November 26–27, 2020.

T. Hayamizu (oral), H. Haba, K. Nakamura, T. Aoki, H. Nagahama, K. Tanaka, N. Ozawa, M. Ohtsuka, and Y. Sakemi, "Development of ultracold francium atomic sources towards the permanent EDM search," Yamada Conference LXXII: The 8th Asia-Pacific Conference on Few-Body Problems in Physics (APFB2020), Kanazawa, Japan, March 1–5, 2021.

[Domestic Conferences/Workshops]

羽場宏光 (招待講演), 「ラジオアイソトープの製造と応用～新元素の探索からがん治療まで～」, 第 17 回日本加速器学会年会, オンライン, 2020 年 9 月 2–4 日.

寺西翔 (口頭発表), 森田涼雅, 早川優太, 坂口綾, 中島朗久, 小森有希子, 横北卓也, 森大輝, 羽場宏光, 横山明彦, 「^{232}Th+^{7}Li 反応の Np 合成系における不完全融合反応の影響」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

森田涼雅 (口頭発表), 寺西翔, 早川優太, 坂口綾, 中島朗久, 小森有希子, 横北卓也, 森大輝, 羽場宏光, 横山明彦 , 「^{232}Th+^{7}Li 反応における反跳率補正による核分裂断面積測定法の確立」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

庭瀬暁隆 (口頭発表), P. Schury, 和田道治, P. Brionnet, S. Chen, 橋本尚志, 羽場宏光, 平山賀一, D. S. Hou, 飯村俊, 石山博恒, 石澤倫, 伊藤由太, 加治大哉, 木村創大, 小浦寛之, J. J. Liu, 宮武宇也, J. Y. Moon, 森本幸司, 森田浩介, 長江大輔, M. Rosenbusch, 高峰愛子, 渡辺裕, H. Wollnik, W. Xian, S. X. Yan, 「MRTOF+α-TOF による ^{257}Db の直接質量測定」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

重河優大 (口頭発表), 山口敦史, 佐藤望, 高峰愛子, 和田道治, 羽場宏光, 「核化学研究用高周波イオン収集システムの開発」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

加藤瑞穂 (口頭発表), 安達サディア, 豊嶋厚史, 塚田和明, 浅井雅人, 羽場宏光, 横北卓也, 小森有希子, 重河優大, Yang Wang, 森大輝, 柏原歩那, 床井健運, 中島朗久, 鈴木雄介, 西塚魁人, 末木啓介, 「HF/HNO_3 系における Db の陰イオン交換挙動」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

横北卓也 (口頭発表), 笠松良崇, 渡邉瑛介, 小森有希子, 重河優大, 森大輝, 王洋, 二宮秀美, 速水翔, 東内克馬, ゴーシュコースタブ, 篠原厚, 羽場宏光, 「硫酸系における Rf の陰イオン交換: 分配係数の硫酸濃度依存性」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

小森有希子 (ポスター発表), 羽場宏光, 「Calix[4]arene-bis(benzocrown-6) を用いた Fr と Cs の溶媒抽出」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

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渡邉瑛介 (ポスター発表), 笠松良崇, 横北卓也, 速水翔, 東内克馬, 重河優大, 羽場宏光, 篠原厚, 「Rf の化学研究に向けた ^{89m}Zr の硝酸系でのオンライン陰イオン交換実験」, 日本放射化学会第 64 回討論会 (2020), オンライン, 2020 年 9 月 9–11 日.

小澤直也 (口頭発表), 長濱弘季, 早水友洋, 中村圭佑, 佐藤幹, 永瀬慎太郎, 小高康照, 鎌倉恵太, 田中香津生, 大塚未来, 青木貴稔, 市川雄一, 高峰愛子, 羽場宏光, 上野秀樹, 酒見泰寛, 「フランシウム原子の電気双極子能率探索のための表面電離イオン源の開発」, 日本物理学会第 76 回年次大会（2021 年）, オンライン, 2021 年 3 月 12–15 日.

[Seminars]

早水友洋, Emily Altiere, Eric R. Miller, David J. Jones, Kirk W. Madison, 百瀬孝昌, 「キセノンの $5p^5 6p \leftarrow 5p^6$ 遷移の高分解能 2 光子分光」, 第 6 回精密計測を元に科学技術に変革をもたらす回路技術調査専門委員会, オンライン, 2021 年 3 月 23 日.

Press Releases

原子 1 つの沈殿を調べる! —超重元素ラザホージウムの共沈挙動の実験的観測—, 理化学研究所, 2021 年 2 月 18 日. https://www.riken.jp/press/2021/20210218_1.

Outreach Activities

羽場宏光, 「原子の仕組みとラジオアイソトープの応用〜新元素の探索からがんの治療まで〜」, 令和 2 年度（2020 年度）八王子市生涯学習センター主催市民自由講座, 八王子, 2021 年 3 月 9 日.