TASCA 22

REC SEP @ SHE CHEM

GSI, Darmstadt, May 10 - 12, 2022
19th Workshop on Recoil Separator for Superheavy Element Chemistry & Physics

Program & Abstracts

Last update: May 06, 2022

Tuesday, May 10, 2022

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15:10	Status report of the JYFL-ACCLAB in-flight separators MARA and RITU (25+5 min)	J. Uusitalo (Univ. of Jyväskylä)	4
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15:45	**Coffee Break**		
	News from Gas-Filled Recoil-Separator Laboratories (Part 2)	**Chair:**	
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14:45	Synthesis of heavy nuclei in multinucleon transfer reaction Xe-136 + U-238 close to zero degrees (25+5 min)	B. Sulignano (CEA / Saclay)	8
15:15	Alpha, photon and electron multi-coincidence spectroscopy with ANSWERS (25+5 min)	P. Mosat (GSI)	9
15:45	Influence of Multi-Neutron Transfer Channels on sub-barrier fusion enhancement (10+5 min)	A. Rani (Univ. of Delhi)	10
16:00	Spectroscopy of neutron deficient actinium isotopes (10+5 min)	J. Louko (Univ. of Jyväskylä)	9
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16:50	Probing proton emitters using MARA sperator (tba) (15+5 min)	K. Auranen (Univ. of Jyväskylä)	12
17:10	Probing the heaviest elements using Penning Trap Mass Spectrometry at SHIPTRAP (25+5 min)	M. Gutiérrez Torres (GSI / HIM)	10
17:40	Probing the fusion-fission dynamics of Bi-203 through mass distribution measurements (10+5 min)	K. Chakraborty (Univ. of Delhi)	12
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14:30	Recent SHE studies utilizing chemical and low-energy ion beam techniques at JAEA (15+5 min)	Y. Ito (JAEA)	14
14:50	Status and Perspectives of the HELIAC-Project (15+5 min)	C. Burandt (TU Darmstadt/GSI)	13
15:10	Ion optical simulation for the NEXT solenoid separator (10+5 min)	A. Soylu (Univ. of Groningen)	15
15:25	Progress report on Laser Resonance Chromatography (LRC) (10+5 min)	Elisa Romero-Romero (JGU / HIM)	15
15:40	**Coffee Break**		
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	Chemistry / Interdisciplinary (Part 2)	**Chair:**	
16:00	Adsorption of superheavy element atoms and molecules on different surfaces (25+5 min)	V. Pershina (GSI)	16
16:30	Status and perspectives of chemistry studies with superheavy elements at the SHE factory in Dubna (25+5 min)	P. Steinegger (PSI)	16
17:00	Towards chemistry beyond moscovium (Mc, Z = 115) (15+5 min)	A. Yakushev (GSI), Y. Wei (Univ. of Mainz)	17
17:20	Metal adsorption on thiolate-functionalized gold-coated silicon detectors for the future study of meitnerium chemistry (10+5 min)	V. Zakusilova (Univ. de Strasbourg / Texas A&M Univ.)	18
17:35	**End of TASCA 22 workshop**		

** Time corresponds to Central European Summer Time (CEST / UTC+02:00)*

Quasielastic backscattering measurement for ^{51}V + ^{248}Cm reaction toward element-119 synthesis at RIKEN

M. Tanaka[1,2] for nSHE collaboration[1-15]

[1] *Kyushu University, Japan;* [2] *RIKEN Nishina Center for Accelerator-Based Science, Japan;* [3] *The Australian National University, Australia;* [4] *Institute of Modern Physics, China;* [5] *Université de Strasbourg, CNRS, IPHC UMR 7178, France;* [6] *Japan Atomic Energy Agency (JAEA), Japan;* [7] *Joint Institute for Nuclear Physics and Applications (JINPA), USA;* [8] *High Energy Accelerator Research Organization (KEK), Japan;* [9] *Niigata University, Japan;* [10] *Oak Ridge National Laboratory, USA;* [11] *Osaka University, Japan;* [12] *Saitama University, Japan;* [13] *Tohoku University, Japan;* [14] *University of Tennessee, Knoxville, Tennessee 37996, USA;* [15] *Yamagata University, Japan*

The periodic table is now completely filled up to the seventh period. The synthesis of elements 119 and 120 has been attempted in several cases using the combination of actinide targets and projectile beams heavier than ^{48}Ca. However, these new elements have not been discovered yet so far.

In the synthesis of superheavy elements, the reaction energy is the most important parameter that significantly affects the experimental efficiency. At RIKEN, element 119 is being searched using a ^{51}V+^{248}Cm hot fusion reaction. The optimal reaction energy of this reaction system is unknown since theoretical predictions vary widely. Under these circumstances, our group has developed a method to estimate the optimal energy from the quasielastic (QE) barrier distribution [1,2].

In our latest study [3], we measured the QE barrier distribution of ^{51}V+^{248}Cm (Fig. 1), using a gas-filled recoil ion separator GARIS-III at a recently upgraded Superconducting RIKEN Heavy Ion LINAC (SRILAC) facility. The energy corresponding to the side collision B_{side}, which is considered to be favorable forming a compound nucleus, was derived from the average barrier height B_0 (Fig. 1(b)), and the optimal reaction energy was estimated based almost purely on experimental evidence. Using the optimal energy obtained in this study, an experiment to synthesize element 119 is currently in progress at RIKEN.

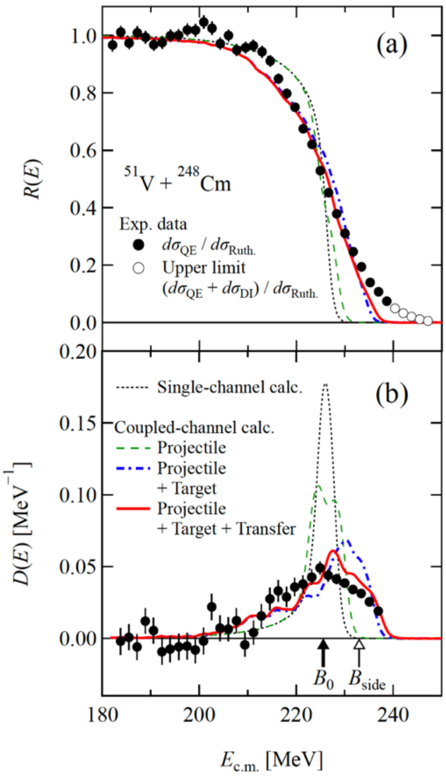

Fig. 1 (a) Excitation function of the QE backscattering cross section relative to the Rutherford cross section for the ^{51}V+^{248}Cm reaction. (b) The QE barrier distribution derived ftom (a).

[1] T. Tanaka et al., J. Phys. Soc. Jpn **87**, 014201 (2018).

[2] T. Tanaka et al., Phys. Rev. Lett. **124**, 052502 (2020).

[3] M. Tanaka et al. for nSHE collaboration, submitted.

Measurement of evaporation residues produced in the multinucleon transfer reaction using the JAEA Recoil Mass Separator

F. Suzaki, K. Nishio, H. Makii, K. Hirose, R. Orlandi, J. Smallcombe

Japan Atomic Energy Agency

Multinucleon transfer (MNT) reaction has attracted attention in the fields of nucleosynthesis and the production of superheavy elements because they can produce nuclei with a large neutron number. To produce desired nuclei efficiently and investigate their nuclear properties, it is necessary to determine the optimal beam and target combination and reaction energy, as well as detection angle. The objective of this study is to measure ER cross sections by changing various experimental conditions in order to establish a reliable theoretical model. We have started a program to study MNT reaction using the JAEA Recoil Mass Separator (JAEA-RMS) [1]. In contrast to kinematic separators dedicated for fusion reaction, the RMS is advantageous as it can rotate around the target chamber, essential for the study of MNT reactions. As a first attempt, we performed the experiment in the reaction of $^{30}Si+^{209}Bi$. The production rate as a function of recoil angle, recoil energy (thus excitation energy), and incident beam-energy dependence were studied. The alpha-decay of the implanted ERs in the focal plane Si detector was observed online. The result is the first to realize the decay measurement in correlated with ERs, produce in the MNT reaction at a finite angle.

[1] H. Ikezoe et al., Nucl. Instrum. Methods Phys. Res. A **376**,420 (1996)

Status report of the JYFL-ACCLAB in-flight separators MARA and RITU

Juha Uusitalo

Nuclear Spectroscopy Group, University of Jyväskylä

The Nuclear Spectroscopy Group (NSG) at JYFL-ACCLAB is employing two complementary in-flight separators in their spectroscopic studies. Recoil Ion Transport Unit (RITU) [1] is a gas-filled recoil separator and has been in operation for almost 30 years. Mass Analyzing Recoil Apparatus (MARA) [2], is a vacuum-mode double focusing mass separator, has been in use for about five years. As said separators are complementary and allow us to perform spectroscopic studies at and beyond the proton-drip line and in the Very Heavy Element (VHE) region starting from mass A= 40 onward. RITU is ongoing a major upgrade where the focal plane system is updated. Detector systems, used at MARA, are composed of particle and gamma-ray arrays for the prompt spectroscopy at the target position and array of silicon detectors combined by germanium detectors for the delayed spectroscopy at the focal plane. Status report and some recent experimental highlights will be presented.

[1] J. Sarén, J. Uusitalo, M. Leino, and J. Sorri, Nucl. Instr. Meth. Phys. Res. A **654**, 508 (2011).

[2] J. Uusitalo, J. Sarén, J. Partanen, and J. Hilton, Acta Physica Polonica B **50**, 319 (2019).

Status and plans for S3

Julien Piot

CNRS/Grand Accélérateur National d'Ions Lourds, Caen, France

The in-depth study of the regions of Superheavy elements and the proton dripline around 100Sn are two major chalenges of todays' Nuclear Physics. Performing detailed spectroscopic studies on these nuclei requires a significant improvement of our detection capabilities.
The Super-Separator-Spectrometer S3 is part of the SPIRAL2 facility at GANIL. Its aim is to use the high stable beam currents provided by the new LINAC to reach rare isotopes by fusion-evaporation. S3 is designed to provide the best rejection power along with a high transmission and a mass resolution of around 400. The use of high-acceptance superconducting multipoles provide a high transmission thanks to large gaps and higher-order optical corrections. These features, connected to a high power target station, will provide access to nuclei with fusion-evaporation cross-section down to the picobarn region and bellow.
S3 is equipped with two complementary detection setup. SIRIUS is designed to study the decay spectroscopy of superheavy nuclei. Its state of the art digital electronics and windowless silicon detectors will provide a high detection efficiency for the identification and alpha decay spectroscopy of short-lived elements combined with an array of high-purity Germanium clover detectors for gamma-ray spectroscopy.
REGLIS3 is a Resonant Laser Ionisation Spectroscopy device designed to study the ground state and isomeric state properties of rare isotopes. The use of narrow bandwidth lasers to select and ionize atoms will provide an additional Z selection and allow to access the spins, moments and charge radius of nuclei transmitted by S3. The high efficiency of the in-gas jet ionization allows to access nuclei in the superheavy and ^{100}Sn region.
This presentation will describe the technical capabilities of S3 and its detection systems, a status of the construction of all systems and give an overview of the Physics Cases planned for the first experiments.

Heavy Element Research at Texas A&M University

C. M. Folden III[1,2]

[1] *Cyclotron Institute, Texas A&M University, College Station, TX 77843-3366 USA*
[2] *Department of Chemistry, Texas A&M University, College Station, TX 77843-3255 USA*

Texas A&M University has a vibrant research program in the areas of online chemistry and nuclear reactions. Recently, our group has been developing organic self-assembled monolayers (SAMs) as surfaces for the adsorption of single atoms. Straight-chain thiols with carefully chosen terminal groups have been self-assembled onto Au-coated Si detectors, which creates a new interaction surface. We have measured the adsorption of Er, Ir, and At on two different SAM surfaces, Au-coated Si, and bare Si in an online experiment. Our group is also studying the influence of deformation on compound nucleus survival in fusion-evaporation reactions. We have measured cross sections for the ^{44}Ca + ^{154,156,157,160}Gd reactions, and the results suggest that collective effects are reducing the survival of the compound nucleus. Finally, our group has worked to install and characterize the gas-filled separator that was previously known as SASSY II. Along with some improvements in the intensity of beams from the Texas A&M K150 cyclotron, these efforts have increased the sensitivity of our accelerator-based experiments. This talk will discuss the most recent results of these experiments and future plans.

Stability of K-isomeric states against fission

J. Khuyagbaatar

GSI Helmholtzzentrum für Schwerionenforschung GmbH

In the last two decades, many isomeric states have been discovered and studied in the region of deformed heavy nuclei with proton and neutron numbers around Z=100 and N=152, respectively [1]. Among these, so-called K-isomeric states [1-3], which formed by coupling of up to several quasiparticles, are of especial interest. In three nuclei ^{270}Ds [4], ^{250}No [5-7], and ^{254}Rf [8], high K isomeric states that are more stable than the respective ground states have been found. Accordingly, K isomeric states, which have extra stability against fission are one of the intriguing topics in both experimental and theoretical study of the superheavy nuclei (SHN).

Theoretically, an effect of the K number on fission is described within various models (e.g., [9-10]) in which results are often lead to or represented an increase of the fission-barrier height compared to that of the ground-state. Such results, indeed, qualitatively describe the extra fission stability of the isomeric state. However, still no quantitative estimates on fission half-lives of various K isomeric states in various SHN are exist. This is related to the complexity of the fission-process description.

In this talk, I will discuss a fission-hindrance due to K quantum number within a recently suggested semi-empirical approach, which had shown to be reasonably effective for descriptions of the electron-capture delayed fission [12] and the spontaneous fission [13]. Estimations on the fission half-lives of excited and high-K states in the SHN will be shown.

For completeness of the topic, I will present experimental results [14-15] on the study of K isomeric states at the gas-filled recoil separator TASCA of the SHE-Chemistry department (GSI).

[1] D. Ackermann and C. Theisen, Phys. Scr. **92**, 083002 (2017).
[2] P. Walker and F. R. Xu, Phys. Scr. **91**, 1 (2016).
[3] G. Dracoulis et al., Rep. Prog. Phys. **79**, 076301 (2016).
[4] S. Hofmann, F.P. Heβberger, et al., Eur. Phys. J. A **10**, 5 (2001).
[5] D. Peterson et al., Phys. Rev. C **74**, 014316 (2006).
[6] A. Svirikhin et al., Phys. Part. Nucl. Lett. **14**, 571 (2017).
[7] J. Kallunkathariyil et al., Phys. Rev. C **101**, 011301 (2020).
[8] H. M. David et al., Phys. Rev. Lett. **115**, 132502 (2015).
[9] F. Xu, E. Zhao, R. Wyss, and P. Walker, Phys. Rev. Lett. **92**, 252501 (2004).
[10] P. Jachimowicz, M. Kowal, and J. Skalski, Phys. Rev. C **83**, 054302 (2011).
[11] H. L. Liu, P. M. Walker, and F. R. Xu, Phys. Rev. C **89**, 044304 (2014).
[12] J. Khuyagbaatar, Eur. Phys. J. A **55**, 134 (2019).
[13] J. Khuyagbaatar, Nucl. Phys. A **1002**, 121958 (2020).
[14] J. Khuyagbaatar et al., Nucl. Phys. A **994**, 121662 (2020).
[15] J. Khuyagbaatar et al., Phys. Rev. C **103**, 064303 (2021).

Laser Spectroscopy of the Heaviest Actinides at GSI

Tom Kieck for the RADRIS Collaboration

GSI Helmholtzzentrum für Schwerionenforschung GmbH & Helmholtz Institute Mainz

Laser spectroscopic measurements of optical transitions in the atomic shell are a well-established tool to study the interaction between the electron shell and the nucleus. To reach the heaviest actinides with their low production rates, the RADRIS (RAdiation-Detected Resonance Ionization Spectroscopy) method is ideally suited.

The first laser spectroscopic investigation of nobelium (Z = 102) applying this technique in a buffer gas-filled stopping cell coupled to the SHIP separator at GSI revealed the shapes and sizes of the nuclei of $^{252\text{-}254}$No [1]. Additionally it enabled high precision measurements of the first ionization potential [2].

Recent technological developments expanded the accessible isotopes, which has allowed the measurement of the ^{248,249,250,254}Fm series across the shell closure at N = 152. In addition, the total efficiency was increased and the alpha detection background level was reduced to the point where a broad search for atomic levels in the heaviest actinide element, lawrencium (Z = 103), became possible. To ensure a traceability for the conditions during the wide wavelength ranges required for this measurement, additional monitoring and documentation of numerous parameters was implemented to enable a reliable evaluation. These developments together with the most recent laser spectroscopic results will be presented.

Additionally, the development of a hypersonic gas jet for laser spectroscopy of the fusion-evaporation products will be discussed, which may improve spectral resolution by an order of magnitude and provide access to even shorter-lived isotopes.

[1] S. Raeder et al., PRL **120**, 232503 (2018).

[2] P. Chhetri et al., PRL **120**, 263003 (2018).

In-beam γ-ray spectroscopy of neutron-rich actinides at the JAEA Tandem accelerator

R. Orlandi [1], H. Makii[1], K. Nishio[1], E. Ideguchi[2], T.T. Pham[2], M. Asai[1], K. Tsukada[1], K. Hirose[1], T.K. Sato[1], Y. Ito[1], F. Suzaki[1], A.N. Andreyev[1,3], N. Aoi[2], T. Shizuma[4], Y. Fang[5], M. Kumar Raju[5], J-G.Wang[5], B. Gao[5], S. Yan[6], K.P. Rykaczewski[7]

[1] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Japan;* [2] *Research Center for Nuclear Physics (RCNP), Osaka University, Japan;* [3] *Department of Physics, University of York, Heslington, United Kingdom;* [4] *National Institutes for Quantum and Radioalogical Science and Technology (QST), Tokai, Japan;* [5] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China;* [6] *China Institute of Atomic Energy, Beijing, China;* [7] *Oak Ridge National Laboratory, Oak Ridge TN, USA*

In the search for the Island of Stability (IoS), indirect information can be obtained by studying actinide isotopes in the region neighbouring the deformed doubly magic nucleus ^{252}Fm (Z=100, N=152). The valence proton and neutron orbitals of nuclei in this region, in fact, include also some substates, lowered by deformation, of those orbits that give rise to the spherical shells of the IoS. The properties of actinides near the deformed shell gaps can thus provide benchmarks for theoretical models that predict the location of the IoS and the properties of Super Heavy Elements [1]. The nuclear structure of neutron-rich actinides, however, is poorly known due to the difficulty of producing and studying these heavy isotopes. At the JAEA Tandem accelerator laboratory in Tokai, Japan, in-beam γ-ray spectroscopy experiments were recently carried out to study the structure of actinides such as ^{248}Cf (Z=98, N=150), ^{249}Cf(Z=98, N=151), ^{254}Es(Z=99, N=155) and ^{252}Fm. The JAEA Tandem is one of the few facilities in the world where radioactive actinide targets can be irradiated using beam of heavy ions. The nuclei of interest were either Coulomb excited (^{249}Cf, ^{254}Es), or produced using transfer reactions induced by heavy-ion beams (^{248}Cf, ^{252}Fm). A brief overview of some recent results and their implications for the deformed shell gaps at Z=100 and N=152 will be presented.

[1] Ch. Theisen *et al.*, Nuclear Physics A **944**, 333–375 (2015).

Synthesis of heavy nuclei in multinucleon transfer reaction Xe-136 + U-238 close to zero degrees

Barbara Sulignano

CEA Saclay, France

Information on the heaviest elements have been obtained up to now via fusion-evaporation reactions. It is however well known that the only nuclei one can reach using fusion-evaporation reactions are neutron deficient and moreover in a very limited number (because of the limited number of beam-target combinations). An alternative to fusion-evaporation can be deep-inelastic collisions. Indeed, theoretical calculations [1] predict large cross-sections for neutron-rich heavy elements production close to zero degrees and recent experiments have been performed showing exciting results [2, 3, 4]. At the end of 2019, we have performed a first preliminary test at Argonne National Laboratory. The goal of the experiment was to investigate deep inelastic reactions mechanisms in the heavy elements region using the Gammasphere germanium array coupled to the AGFA (Argonne gas-filled analyzer) separator with the implantation-decay station (PPAC, DSSD and silicon tunnels) and germanium clover detectors XArray at the focal plane.
In this talk I will report on the result obtained in the test experiments and I will give you some details about the further experiments and developments planned.

[1] V.I. Zagrebaev and W. Greiner. Nucl. Phys. A, 944:257-307, 2015.

[2] S. Heinz et al. Eur. Phys. J. A, 52:278, 2016.

[3] A. Di Nitto et al. Phys. Let. B, 784:199-205, 2018.

[4] J.S. Barrett et al. Phys. Rev. C, 91:064615, 2015.

Alpha, photon and electron multi-coincidence spectroscopy with ANSWERS

J. Khuyagbaatar[1], P. Mosat[1] & A. Yakushev[1] for the SHE chemistry department

[1]*GSI Helmholtzzentrum für Schwerionenforschung GmbH*

A new adsorption-based technique for the nuclear spectroscopy was introduced in 2020 [1] at the SHE Chemistry department, GSI. In this technique, particles and photons emitted in the radioactive decays of heavy nuclei are measured with large efficiencies by an assembly of Si (R&D project with the Łukasiewicz—Institute of Electron Technology, Warsaw, Poland) and Ge (MIRION) detectors, respectively, which is called ANSWERS (Adsorption-based Nuclear Spectroscopy Without Evaporation Residue Signal).

In this talk the performance of the ANSWERS for the multi-coincidence alpha, photon and electron spectroscopy will be demonstrated on the example of ^{211}Bi [2]. Also the experimental results from the successful commissioning of the ANSWERS at the gas-filled recoil separator TASCA for the study of the well-known decay of ^{253}No [3–7] will be presented.

We are grateful for GSI's the Experimental Electronics department and Target Lab for their continuous support of the experimental program at TASCA. We acknowledge the ion-source and UNILAC staff for providing the stable and high intensity ^{48}Ca beam. The results for ^{253}No is based on the experiment U308, which was performed at the beam line X8/TASCA at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

[1] J. Khuyagbaatar, A. Yakushev, et al., to be published.
[2] P. Chhetri et al., PRL **120**, 263003 (2018).
[3] R.-D. Herzberg, Journal of Physics G: Nuclear and Particle Physics **30**, R123 (2004).
[4] F. P. Heßberger, S. Hofmann, D. Ackermann, et al., European Physical Journal A **22**, 417 (2004).
[5] A. Lopez-Martens, K. Hauschild, A. V. Yeremin, et al., Physical Review C **74**, 044303 (2006).
[6] A. Lopez-Martens, T. Wiborg-Hagen, K. Hauschild, et al., Nuclear Physics A **852**, 15 (2011).
[7] F. P. Heßberger, S. Antalic, D. Ackermann, et al., European Physical Journal A **48**, 75 (2012).

Spectroscopy of neutron deficient actinium isotopes

J. Louko [1], Nuclear Spectroscopy Group [1]
Supervisors: J. Uusitalo [1], K.Auranen [1]

[1]*Accelerator Laboratory, Department of Physics, University of Jyväskylä, Jyväskylä, Finland*

Prompt and delayed spectroscopy of neutron deficient actinium isotopes was performed at JYFL-ACCLAB. Recoils produced in fusion-evaporation reactions were separated from the beam and unwanted products using MARA vacuum mode recoil separator and subsequently tagged at focal plane using recoil-α decay method. In-beam γ-ray spectroscopy could then be performed for selected recoils by looking back at events seen in JUROGAM III spectrometer. Possible delayed γ-rays were detected by focal plane HPGe-detectors. Excited states in trans-lead nuclei offer an important experimental fingerprint about the onset of nuclear deformation. Past studies have shown that many nuclei in this region exhibit longer living isomers as well as shears bands [1][2]. These were also expected to be present in actiniums, but no supporting evidence was found in this experiment. However, it was confirmed that a more established phenomenon seen in the spherical and nearly spherical astatine and francium nuclei, in which the low-lying negative parity states follow the systematics of the 2^+, 4^+ and 6^+ states of the respective even-even isotone core, also applies to actiniums.

[1] G. D. Dracoulis *et al.*, *Rep. Prog. Phys.* **79,** 076301 (2016).
[2] R. M. Clark and A. O. Macchiavelli, Annu. Rev. Nucl. Part. Sci. **50**, 1 (2000).

Influence of Multi-Neutron Transfer Channels on sub-barrier fusion enhancement

Anjali Rani[1], S. Mandal[1], K. Chakraborty[1], R. Gupta[1], C.V Ahmad[1], A. Parihari[1], D. Vishwakarma[1], P. Khandelwal[1], P. S. Rawat[1], P. Sherpa[1], S. Kumar[1], N. Madhavan[2], S. Nath[2], J. Gehlot[2], Gonika[2], Rohan Biswas[2], Chandra Kumar[2], Shoaib Noor[3]
Supervisor: S. Mandal[1]

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Heavy ion fusion reaction dynamics in the vicinity of the Coulomb barrier have been extensively explored over the past few decades. The fusion cross sections at sub-barrier energies in the literature have been found to be enhanced over the predictions of One Dimensional Barrier Penetration Model (1-D BPM) calculations [1]. The effect of positive Q value Neutron Transfer (PQNT) channels on the sub-barrier fusion enhancement is still elusive in most of the cases. Therefore, in order to ascertain the aforementioned aspects, fusion excitation function measurements from ~15 % below and above the Coulomb barrier have been performed for **^{28}Si + ^{116,120,124}Sn** systems using the Heavy Ion Reaction Analyzer (HIRA) at Inter University Accelerator Centre (IUAC), New Delhi. The experimentally measured fusion cross sections for all three Sn isotopes around the Coulomb barrier have been found to be enhanced as compared to uncoupled calculations. Coupled-Channels (CC) formalism has been employed to probe the underlying reaction mechanism [2]. The effect of Multi-Neutron Transfer (MNT) channels on sub-barrier fusion enhancement has been highlighted. Further, fusion barrier distribution have also been derived from the experimental data to understand the dynamics of the various channels coupled in the reaction. Detailed analysis and results will be presented during the conference.

[1] M. Dasgupta et al., Ann. Rev. Nucl. Part. Sci. 48, 401 (1998).
[2] K. Hagino *et al.*, Comput. Phys. Commun. 123, 143 (1999).

Probing the heaviest elements using Penning Trap Mass Spectrometry at SHIPTRAP

Manuel J. Gutiérrez on behalf of the SHIPTRAP collaboration

GSI Helmholtzzentrum für Schwerionenforschung GmbH & Helmholtz Institute Mainz

The elements with atomic numbers Z>103, called Superheavy Elements (SHEs) owe their existence to the quantum-mechanical shell effects that increase their stability. The SHIP separator at GSI, stage of the discovery of elements with Z=107–112, has since been exploited in further investigations of the nuclear structure of such exotic systems. In particular, mass measurements using the coupled Penning trap setup SHIPTRAP has allowed a direct determination of binding energies of the lighter superheavy nuclides, providing insight on the shell evolution around N=152.
Recent experiments within the recent FAIR Phase-0 campaigns have resulted in measurements of ^{257}Rf, with rates of a few ions per day, as well as ^{258}Db. This was made possible by improvements in the efficiency of the setup. Furthermore, isomeric states of ^{251,254}No, ^{254,255}Lr, ^{257}Rf and ^{258}Db have been resolved thanks to mass resolving powers up to 11 000 000, enabled by the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique. This cements PI-ICR as a complementary tool to decay spectroscopy, especially in cases where the complexity of the decay spectra demands additional information to disentangle the level structure. This was further proven by the study of several additional species above the Z=82 shell closure.
In this contribution an overview of the results of the last online campaign will be presented, as well as the latest technical developments to allow longer experiments without suffering of efficiency degradations of the setup, which is the limiting factor when addressing more exotic nuclides.

Multinucleon transfer reactions in the ^{238}U + ^{238}U system studied with the VAMOS + AGATA + ID-Fix

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Since the middle of the last century many efforts have been devoted to investigate the region of heaviest nuclei. Various models predict an existence of the island of stability of superheavy nuclei (SHN) with shell closure at a proton number between 114 and 126 and at a neutron number 172 or 184 [1]. However, the discovery of these nuclei is an experimental challenge. Also, the region of neutron-rich light actinides (uranium region) in the vicinity of the N = 152 deformed shell gap, where important nuclear structure features are expected, is beyond reach. The fusion-evaporation reaction, being so far successful in synthesis of SHN, faces significant limitations caused by low production cross sections and the lack of sufficiently neutron-rich projectile-target combinations. An alternative way to approach this region has been proposed via the employment of multinucleon transfer (MNT) reactions for which rather high cross sections were predicted in near-barrier deep-inelastic collisions of heavy ions [2,3]. Experimentally, the production of neutron-rich actinide nuclei up to Fm was observed via chemical separation techniques in cross section values ranging from mbarn to nbarn [4]. Within this context, an experiment aiming to investigate the MNT cross sections of exotic neutron-rich light actinides in the reaction of $^{238}U+^{238}U$ was carried out at GANIL in May 2021. The measurement was performed employing the VAMOS++ magnetic spectrometer for the atomic mass identification, the AGATA γ -ray spectrometer and the x-ray detection array ID-Fix for the identification of the atomic number through x-ray spectroscopy. In the talk, I will focus on the work done for preparation of the detection setup, in terms of absorber studies for a photon background from the $^{238}U+^{238}U$ reaction and optimization of the digital pulse processing for an efficient X-ray spectroscopy, and will report on preliminary results on the $^{238}U+^{238}U$ experiment.

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[2] V.I. Zagrebayev et al., Phys. Rev. C **73**, 031602(R) (2006)

[3] V.I. Zagrebayev et al., Phys. Rev. C **87**, 034608 (2013)

[4] M. Schädel et al., Phys. Rev. Lett. **41**, 469 (1978)

Probing proton emitters using the MARA separator

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Using the fusion-evaporation reaction ^{96}Ru(^{58}Ni,$p4n$)^{149}Lu and the MARA vacuum-mode recoil separator we have identified a new proton-emitting isotope ^{149}Lu. The measured decay Q-value of 1920(20) keV is the highest measured for a ground-state proton decay, and it naturally leads to the shortest *directly* measured half-life of 450^{+170}_{-100} ns for a ground-state proton emitter. The decay rate is consistent with $l_p = 5$ emission, suggesting a dominant $\pi h_{11/2}$ component for the wave function of the proton-emitting state. Through non-adiabatic quasiparticle calculations we were able to conclude that ^{149}Lu is the most oblate deformed proton emitter observed to date. In this talk I will discuss the experimental details and the already published results [1]. Additionally, we collected a good number of recoil-decay tagged γ rays feeding the proton decaying ^{147}Tm and ^{147m}Tm. The preliminary level schemes extracted from these data are also presented and discussed.

[1] K. Auranen et al., PRL **128**, 112501 (2022).

Probing the fusion-fission dynamics of ^{203}Bi through mass distribution measurements

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One of the primary objectives to explore heavy-ion induced fusion reactions is to synthesize superheavy elements (SHEs), not present on earth in natural form. The main hindrance in the production of SHEs is the dissociation of the di-nuclear composite system into projectile-like and target-like fragments before it reaches equilibrium which leads to quasifission (QF). Non-equilibrium fission has been observed in nuclei as light as ^{200}Pb with $Z_PZ_T < 700$ (Z_P and Z_T are the atomic charges of the projectile and target, respectively) which is much lower than the threshold value (≥1600) for the onset of QF as per Swiatecki's dynamical model [1]. Further, the suppression in ER cross-sections, one of the signatures of non-equilibrium processes, for the reaction ^{19}F + ^{184}W populating ^{203}Bi as reported by Nath *et al*. [2] prompted us to implore the mentioned reaction through a different experimental observable, fission fragment mass distribution which is a well established method to ascertain the presence or absence of QF in a reaction. The experimental work has been carried out at Inter University Accelerator Centre, New Delhi, India. After populating ^{203}Bi in the excitation energy range of 80-110 MeV, its fragment mass distribution has been extracted through two large area (20 ×10 cm^2) Multi-Wire Proportional Counters kept at folding angles. The variance of the width of the fragment mass distribution with excitation energies has been studied to examine the deviation, if any, from complete equilibriation. Detailed results will be presented during the workshop.

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Upgrade of the detection setup of the gas-filled recoil separator GARIS-III

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The upgrade of the GARIS-III detection system was part of the overall upgrade of the experimental, with the newly developed superconducting RIKEN linear accelerator (SIRALC). The new superconductive tank, new 28 GHz SC–ECRIS ion source and overall higher beam energy/intensity available triggered a series of upgrade and new development of the detection setup of GARIS-III focal plane system: new detectors array and development of a digital acquisition electronics.
The complete silicon detector array has been replaced with new generation of Hamamatsu detectors. They have been developed in direct collaboration with the RIKEN team to fit the specification of our setup: 12x6cm^2 DSSDs surrounded by pixelized Side/Veto detectors. The full characterization of these detector is currently ongoing (resolution, dead layer, …). The preliminary results indicate around 100 nm of dead layer measured on the side detectors. The preliminary optimization and characterization of these detector will be presented during this talk.
In addition, to the upgrade of the detector system, the transition to a digital electronic acquisition is also ongoing on the GARIS-III setup. This transition, coupled with the previous upgrade to fast CREMAT Inc. preamplifier (CR-110 and CR-111), lead to the reduction of the overall dead time of the detection setup bellow 100 ns (64 ns achieved in beam). This reduction led to the identification of very fast decays of reaction products in the region north-east of the ^{208}Pb. In addition, an increase of the energy resolution of about 5 keV on the average FWHM has also been observed compared to its analog counterpart. This transition to a digital electronic also opened the door the pulse shape analysis for the reduction of the background in the alpha spectrum. The preliminary results of this pulse shape analysis will be presented in addition to the results on the development and optimization of the in-beam condition for the digital electronic.

Status and Perspectives of the HELIAC-Project

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The linear accelerator HELIAC will provide heavy ions with particle energies of 3.5 MeV/u to 7.6 MeV/u (A/Z = 6) at the *GSI Helmholtzzentrum für Schwerionenforschung*. Thanks to supercon-ducting radio-frequency technology, it will be able to deliver high average beam currents in continuous-wave mode.
The radio-frequency resonators of the so-called Cross-bar H-mode type are being developed in cooperation with the IAP of *Goethe University Frankfurt*. The suitability of these resonators in principle for ion beam acceleration was successfully demonstrated in an earlier phase of the project. In the current, advanced demon-stration stage an extended beam test with a first fully equipped series cryomodule is to take place shortly at GSI. The infrastructure for this has been created in recent years. In addition to setting up a radiation-shielding area with a link to the existing 4 K helium liquefier on site, this also includes vital preparations at the *Helmholtz Institute Mainz*. There, the superconducting resonators were tested for their performance one at a time and a spacious ISO-class 4 clean room providing the high-purity environment required for the adequate assembly of superconducting RF structures was commissioned.
This talk will present the current status of the project and recent activities, as well as the design of the complete HELIAC accelerator.

Recent SHE studies utilizing chemical and low-energy ion beam techniques at JAEA

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At the JAEA tandem accelerator facility, we are conducting experiments on nuclear chemistry and physics of heavy elements and developing associated apparatuses, utilizing the ability to use a variety of actinide targets and the abundance of available beam time.

In recent years, for chemistry studies, we developed an online isothermal gas-chromatographic device [1,2] and investigated the volatility of dubnium (Db, element 105) in the form of its oxychloride, $DbOCl_3$ [3]. For physics studies, we have obtained einsteinium (Es, element 99) material in 2017, 2019, and 2021 from Oak Ridge National Laboratory and carried out spontaneous fission studies of fermium (Fm, element 100) and mendelevium (Md, element 101) isotopes with an aerosol gas-jet coupled surface ion source (SIS) [4] followed by the Isotope Separator On-Line (ISOL) and the MANON detector system utilized for the first ionization potential (IP) measurements [5,6].

Towards future experiments at ISOL, we are developing a new ion source based on the Electron Beam Generated Plasma (EBGP) method [7]. The ion source will be used for the ionization of high-IP atoms/molecules such as a rutherfordium (Rf, element 104) halide which is difficult to ionize with the present SIS. Another development is a construction of a low-energy ion beamline at ISOL. We commissioned a Gas Cell ion beam Cooler and Buncher (GCCB) [8] using short-lived actinides and successfully converted 30 keV ISOL beams to low-energy ion beams which can be stored in an ion-trap based devices such as an MRTOF mass spectrograph.

In this talk, a status report of the activities above and prospects related to the future experimental program will be given.

[1] N.M. Chiera et al., J. Radioanal. Nucl. Chem. 320, 633 (2019)

[2] N.M. Chiera et al., Inorg. Chem. Acta 486, 361 (2019)

[3] N.M. Chiera et al., Angew. Chem. Int. Ed. 60, 17871 (2021)

[4] T.K. Sato et al., Rev. Sci. Instrum. 84, 023304 (2013)

[5] T.K. Sato et al., Nature 520, 209 (2015) 209

[6] T.K. Sato et al., J. Am. Chem. Soc. 140, 14609 (2018)

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[8] Y. Ito et al., JPS Conf. Proc. 6, 030112 (2015)

Ion optical simulation for the NEXT solenoid separator

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The NEXT project aims to study **N**eutron-rich, **EX**otic, heavy nuclei produced in multi-nucleon **T**ransfer reactions[1]. Part of the NEXT setup is a 3T solenoid magnet with a 90-cm wide bore. The magnet will be used to focus the transfer products of interest and to separate those from unwanted by-products as well as from the unreacted primary beam.
Within this contribution, we present a Python code which we developed to simulate the paths of ions through the magnetic field of the solenoid. The goal of the simulation is to determine the optimal layout of the separator in order to achieve highest transmission efficiencies and strongest background suppression.
The simulation requires a realistic description of the magnetic field in- and outside the solenoid. For this purpose, we implemented an interpolated model. The trajectories of the ions through the magnetic field are determined through their emitting angles and magnetic rigidities. Therefore, we implemented the calculation of the charge state distribution in the code. As input data, our code requires the differential cross-section, the kinetic energies, and the emitting angels of the transfer products.
So far, we have investigated two reactions[2] in order to optimize the layout of the NEXT separator:

- ^{136}Xe+^{198}Pt at 6 MeV/u to produce nuclei around the N=126 shell closure
- ^{48}Ca+^{251}Cf at 6.1 MeV/u to produce nuclei in the transfermium region

We will present the results of the simulations.

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[2] Karpov, A.; Saiko, V., Phys. Part. Nucl. Lett 2019, 16, 667–670 & EPJ Web of Conf. 2017,163.

Progress report on Laser Resonance Chromatography (LRC)

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The research of superheavy elements has been an exciting endeavour for scientists for many decades, as it enables probing the limits of nuclear existence and provides a fertile ground to advance our understanding of the atom's structure. However, the experimental access to these atomic species is very challenging and often requires the development of new technologies and experimental techniques optimized for the study of a single atomic species. Laser Resonance Chromatography (LRC) technique, was conceived to enable atomic structure investigations in the region of superheavy elements [1,2]. Here, we give an update on the experimental progress, simulations, and initial experimental results.

[1] J. Reader A. Kramida, Yu. Ralchenko and NIST ASD Team (2018), 2019.
[2] M. Laatiaoui et al., Physical Review Letters 125.2 (2020): 023002.

Adsorption of superheavy element atoms and molecules on different surfaces

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The present work is a continuation of our research on adsorption of superheavy elements (SHEs) on surfaces of detectors of a chromatography column used in gas-phase experiments.[1] This time, adsorption energies, E_{ads}, and other properties of atoms and oxides of Cn and Fl, as well as of homologous species of Hg and Pb, on the Au(111) and hydroxylated quartz surfaces are predicted on the basis of 2c-DFT calculations and a periodic slab model using the BAND software. The ambition of the work is to interpret the outcome of the "one-atom-at-a-time" gas-phase chromatography experiments on reactivity/volatility of Fl.[2] A significant difference in the adsorption strength was found between the elements and their oxides. Also, geometries of the adsorbed MO species were shown to be very different between group 12 and 14.

Some new aspects for adsorption of group 13 elements, Tl and Nh, on hydroxylated quartz surfaces are discussed.

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[2] A. Yakushev, et al., Chem. Phys. Chem., submitted

Status and perspectives of chemistry studies with superheavy elements at the SHE factory in Dubna

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Here, we present the status and prospects of superheavy element research at the Flerov Laboratory of Nuclear Reactions (FLNR) and at the Paul Scherrer Institute (PSI). Firstly, we will discuss the preparations and detailed plans for the first chemistry experiment (i.e., elemental copernicium and flerovium) at the Superheavy Element Factory (SHE Factory) of the FLNR. In a second part, the progress regarding high-temperature alpha-spectroscopy will be shown. Higher stationary surface temperatures beyond 50°C (i.e., current limit with Si-based solid-state detectors), are of particular importance for the study of heaviest superheavy elements (e.g., nihonium) as well as relatively less volatile chemical elements and their compounds.

Towards chemistry beyond moscovium (Mc, Z = 115)

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Chemical studies are a hot and challenging topic in the superheavy element (SHE) research field. The drastically decreasing production cross sections and half-lives with increasing proton number result in a small number of detected events. The chemical study of volatile superheavy elements Cn (Z = 112) and Fl (Z = 114), which have closed electron-shell configurations $6d^{10}7s^2$ and $7s^27p_{1/2}{}^2$, respectively, were performed on the statistical level of a few atoms only [1-3]. The neighboring element Nh (Z = 113) has one unpaired electron on the valence shell, and thus, should have a higher chemical reactivity, as predicted by recent theoretical calculations [4, 5]. First attempts to chemically study Nh have confirmed its higher reactivity compared to Cn and Fl [6-8] and called for new developments, which would allow to separate and detect short-lived and chemically reactive elements, including Nh, and Mc (Z =115) [8].
However, a significantly faster extraction technique is needed for heavier elements, e.g., Lv (Z = 116) and Ts (Z =117). Here, we present the design, simulations, and the development of a new experimental setup for SHE chemistry, which is based on the compact buffer gas stopping cell UniCell [9] and the miniCOMPACT chromatography and detector system.

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[2] R. Eichler et al.: *Indication for a volatile element 114*. Radiochim. Acta **98**, 133-139 (2010).
[3] A. Yakushev et al.: *Superheavy element Flerovium (element 114) is a volatile metal*. Inorg. Chem. **53**, 1624-1629 (2014).
[4] L. Trombach, S. Ehlert, S. Grimme, P. Schwerdtfeger, and J.-M. Mewes.: *Exploring the chemical nature of super-heavy main-group elements by means of efficient plane-wave density-functional theory*. Phys. Chem. Chem. Phys. **21**, 18029–18408 (2019).
[5] V. Pershina, M. Iliaš, A. Yakushev.: *Reactivity of the Superheavy Element 115, Mc, and Its Lighter Homologue, Bi, with Respect to Gold and Hydroxylated Quartz Surfaces from Periodic Relativistic DFT Calculations: A Comparison with Element 113, Nh*. Inorg. Chem., **60**, 9848-9856 (2021).
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[7] N. V. Aksenov et al.: *On the volatility of nihonium (Nh, Z = 113)*. Eur. Phys. J. A **53**, 158 (2017).
[8] A. Yakushev et al.: *First attempt to study nihonium (Nh, Z = 113) chemically at TASCA*. Front. Chem. **9**, 753738 (2021).
[9] V. Varentsov and A. Yakushev: *Concept of a new Universal High-Density Gas Stopping Cell Setup for study of gas-phase chemistry and nuclear properties of Super Heavy Elements (UniCell).* Nucl. Instrum. Meth. A **940**, 206-214 (2019).

Metal adsorption on thiolate-functionalized gold-coated silicon detectors for the future study of meitnerium chemistry

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In the field of heavy elements, one of the first attempts to use gold-coated silicon was reported during the chemical characterization of element 112, Cn [1]. Better chemical sorption of this element was observed on gold-modified surfaces rather than on non-modified ones. In the case of element 113, Nh, an enhanced reactivity towards gold was observed, which prevented the proper chemical characterization of this element [2]. Thus, a need for new chemically modified silicon detectors has emerged. The purpose of such surfaces is to selectively bind the atoms of interest but with weaker interactions. Meitnerium, which is expected to be a member of Group IX of the periodic table, has never been chemically characterized before. In this project, the adsorption of iridium (meitnerium's lighter homolog), as well as erbium (a non-volatile element) and astatine (a volatile element) on thiolate-functionalized gold-coated silicon detectors have been studied during online cyclotron-based experiments. The poster will discuss the effect of the surface chemical composition, and the detector position in a simple Recoil Transfer Chamber on the yield of radionuclides. Also, the poster will include studies on the self-assembly of the used thiols on gold-coated silicon substrates. The functionalized substrates were characterized via atomic force microscopy, cluster secondary-ion mass spectrometry, X-ray photoelectron spectroscopy, ellipsometry, and neutron activation analysis

[1] R. Eichler *et al.*, Nature **447**, 72 (2007).
[2] A. Yakushev *et al.*, Front. Chem. **9**, 1 (2021).