TASCA 14

13th Workshop on

Recoil Separator for Superheavy Element Chemistry

October 21, 2014, GSI, Darmstadt, Germany

supported by the JAEA ASRC's Reimei program

Final Program and Abstracts

October 20, 2014

TIME	TOPIC
19:00	**Optional: Dinner at "Bürgermeister-Pohl-Haus", Wixhausen (registration required)**

October 21, 2014

TIME	TOPIC	Speaker	Page
09:00	Welcome	**Boris Sharkov** Chairman/Scientific Managing Director FAIR	
	Scientific highlights from gas-filled (and other) separators	**Chair:**	
09:10	Present status and future plans of SHE researches at RIKEN	H. Haba (RIKEN)	2
09:35	First synthesis and investigation of $Sg(CO)_6$	J. Even (HIM)	3
10:00	Probing the coexisting shapes at the proton drip line	J. Uusitalo (JYFL)	9
10:25	**Coffee**		
10:45	Results from the $^{48}Ca+^{243}Am$ experiments at TASISpec *- - cancelled - -*	D. Rudolph (Lund Univ.)	3
11:10	Decay Study of ^{258}Db at SHIP	F.P. Hessberger (GSI)	4
11:35	First ionization potential measurement of lawrencium (Lr, Z=103)	T. Sato (JAEA Tokai)	4
12:00	**Lunch**		
13:00	**Workshop Photo**		
	Chemistry developments for future SHE experiments	**Chair:**	
13:15	Formation of Mo/W carbonyls by means of laser-ablation method	Q. Zhi (IMP)	-
13:40	Group VI metal hexacarbonyl complexes: production, decomposition, modeling	I. Usoltsev (PSI)	5
14:05	Studies of flerovium homologs with macrocyclic extractants	J. Despotopulous (LLNL)	6
14:30	**Coffee**		
	Facilities and technical developments	**Chair:**	
14:50	SHELS - Separator for Heavy ELement Spectroscopy	A. Popeko (FLNR)	7
15:15	Superheavy elements at GANIL	J. Piot (GANIL)	8
15:40	A compact decay spectroscopy set-up for SHN research	D. Ackermann (GSI)	8
16:05	Status of the sc cw LINAC Demonstrator project	V. Gettmann (GSI)	9
16:30	Closing remarks		
16:40	End of TASCA 14 workshop		

All presentations include 10 min. discussion time

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Present status and future plans of SHE researches at RIKEN

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Present status and perspectives of superheavy element (SHE) researches at RIKEN are reviewed.
We developed a gas-jet transport system coupled to the GAs-filled Recoil Ion Separator GARIS at the RIKEN Linear Accelerator as a novel technique for SHE chemistry. The isotopes of ^{261}Rf, ^{262}Db, and ^{265}Sg useful for chemistry studies were produced in the ^{248}Cm(^{18}O,5*n*), ^{248}Cm(^{19}F,5*n*), and ^{248}Cm(^{22}Ne,5*n*) reactions, respectively, and they were extracted to a chemistry laboratory by the gas-jet method after the separation by GARIS [1–3]. The production and decay properties of those isotopes were investigated in detail for future chemistry studies using a rotating wheel apparatus for α and SF spectrometry. In the workshop, preliminary results on the production of Bh isotopes in the ^{248}Cm(^{23}Na,*xn*) reactions will be also presented.
We also installed a conventional gas-jet chamber for SHE production in the beam line of the AVF cyclotron. Aqueous chemistry experiments with ^{261}Rf and ^{262}Db have been conducted using the Automated Rapid Chemistry Apparatus (ARCA) of JAEA, the AutoMated Batch-type solid-liquid Extraction apparatus for Repetitive experiments of transactinides (AMBER) of Osaka Univ., and a computer-controlled suction filtration apparatus for the preparation of precipitated samples of heavy elements (CHIN) of Osaka Univ.
After the observation of the third decay chain of element 113, ^{278}113, in the cold fusion reaction of ^{209}Bi(^{70}Zn,*n*)^{278}113 [4], we started syntheses of the heavier SHEs by hot fusion reactions. As the first step, the isotopes of element 116, ^{292,293}Lv, were produced in the ^{248}Cm(^{48}Ca,*xn*)$^{296-x}$Lv reactions [5] to confirm those observed at Dubna [6,7] and GSI [8]. In 2015, the ^{248}Cm(^{50}Ti,*xn*)$^{298-x}$118 reactions are planned to be studied.

References

[1] H. Haba *et al.*, Phys. Rev. C **83**, 034602 (2011).
[2] H. Haba *et al.*, Phys. Rev. C **85**, 024611 (2012).
[3] H. Haba *et al.*, Phys. Rev. C **89**, 024618 (2014).
[4] K. Morita *et al.*, J. Phys. Soc. Jpn. **81**, 103201 (2012).
[5] K. Morita *et al.*, RIKEN Accel. Prog. Rep. **47** (in press).
[6] Yu. Ts. Oganessian *et al.*, Phys. Rev. C **63**, 011301(R) (2000).
[7] Yu. Ts. Oganessian *et al.*, Phys. Rev. C **70**, 064609 (2004).
[8] S. Hofmann *et al.*, Eur. Phys. J. A **48**, 62 (2012).

First synthesis and investigation of $Sg(CO)_6$

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In the past decades, only simple inorganic compounds of SuperHeavy Elements (SHE) were studied in gas-phase chemical reactions[1]. Accessing new compound classes was impossible mainly due to technical restrictions. Thanks to the approach of physical preseparation [2], many limitations could be overcome. We have developed in experiments at the TRIGA reactor in Mainz and at the TASCA separator at GSI a method to synthesize carbonyl complexes of short-lived isotopes [3]. This method has now been successfully applied at the GARIS separator at RIKEN to synthesize for the _rst time a carbonyl complex of a superheavy element - Seaborgium hexacarbonyl [4].
^{265}Sg was synthesized in the reaction ^{248}Cm(^{22}Ne,5n) [5], separated from the primary beam, and was thermalized in a He/CO mixture behind GARIS. This way it formed a volatile complex and was transported in the gas stream to a COMPACT gas-chromatography detector[6], where its adsorption on SiO_2 was studied. The chemical properties of seaborgium were compared to its lighter homologs molybdenum and tungsten. The combination of physical and chemical separation allowed studying the decay of ^{265}Sg under background-free conditions. Our results indicate the observation of $Sg(CO)_6$ and provide new information on the nuclear properties of ^{265}Sg.

References

[1] A. Türler and V. Pershina, Chem. Rev. 113, 1237-1312(2013).
[2] Ch. E. D ullmann et al., Nucl. Instr. Meth. A 551, 528539(2005).
[3] J. Even, et al., Inorg.Chem. 51, 6431-6422 (2012).
[4] J. Even et al, Science 345, 1491-1493 (2014).
[5] H. Haba et al., Phys. Rev. C 85, 024611(2012).
[6] A. Yakushev et al., Inorg. Chem. 53, 1624 (2014).

Results from the ^{48}Ca + ^{243}Am experiment at TASISpec

D. Rudolph
on behalf of the TASISpec Collaboration

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The reaction ^{48}Ca + ^{243}Am, leading to element 115, was investigated with the multi-coincidence spectroscopy set-up TASISpec placed in the focal plane of TASCA. First candidates for *X*-ray fingerprinting of element 115 descendants were observed, likewise *X*-ray transitions along the five-α-long decay chains starting from ^{288}115. The latter put serious contraints on nuclear structure models. Seven shorter correlated decay chains of types recoil- α -fission (2) and recoil- α - α -fission (5) put the links between ^{293}117 and ^{289}115 proposed by the Dubna collaborations into doubt. The present status of the results will be presented.

Decay Study of ^{258}Db at SHIP

F.P. Heßberger

GSI Darmstadt and Helmholtz Institut Mainz

An experiment to study the decay properties of ^{258}Db was performed at SHIP in May 2014. The isotope was produced in the reaction ^{209}Bi(^{50}Ti,n)^{258}Db.
The aim of the experiment was threefold:

- To disantangle the puzzling α-decay spectrum of ^{258}Db measured in previous experiments at SHIP, which gave a hint to two states having similar half-life and decaying by α-emission and/or EC [1].
- To directly prove EC decay of ^{258}Db by measuring delayed coincidences between K-X-rays and fission of the EC daughter ^{258}Rf.
- To measure the <TKE> of fission of ^{258}Rf and to use the known literature value [2] as a calibration factor to estimate <TKE> of the neighbouring isotopes ^{256}Rf and ^{255}Rf, which were produced in the same experimental run in the reactions ^{208}Pb(^{50}Ti,2n)^{256}Rf and ^{207}Pb(^{50}Ti,2n)^{255}Rf.

The present status of the data evaluation will be reported.

References

[1] F.P. Heßberger et al., EPJ A41, 145 (2009)
[2] J.F. Wild et al., Journ. of Alloys and Compounds 213/214, 86 (1994)

The First Ionization Potential Measurement of Lawrencium (Lr, Z = 103)

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Lawrencium (Lr, Z = 103) is expected to be the first element in which a 7*p* orbital appears in the valence electronic orbital of its ground state, caused by strong relativistic effects [1]. In order to determine the first ionization potential (IP) value of Lr experimentally, we have developed a surface ionization type ion-source coupled to a gas-jet transport system [2]. Using the present system, we carried out a measurement of the IP value of Lr based on the dependence of an ionization efficiency on IP in the surface ionization process.
In the presentation, the first experimental determination of the IP value of Lr will be reported.

References

[1] A. Borschevsky et al., Eur. Phys. J. D 45, 115-119 (2007).
[2] T. K. Sato et al., Rev. Sci. Instr. 84, 023304 (2013).

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Group VI Metal Hexacarbonyl Complexes: production, decomposition, modeling.

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Recent synthesis of $Sg(CO)_6$ provided chemistry of superheavy elements with a first compound of Sg in its zero oxidation state. Relativistic calculations predict similar stability of W-CO and Sg-CO bonds in the corresponding hexacarbonyl complexes. In this report we suggest an experimental approach and its modeling, which would allow for testing the prediction. Implementation of a tubular flow reactor (decomposition column), covered with silver, is shown to be effective to distinguish between the stability of $Mo(CO)_6$ and $W(CO)_6$. The stability of the complexes is accessed through their decomposition behavior. The decomposition process can be modeled by a newly developed microscopic Monte-Carlo adsorption model, superimposed by a first order decomposition reaction with activation energies equal to the first-bond-dissociation enthalpy. Thus, the Me-CO bond formation enthalpy can be gained from a least square fit of experimental decomposition curves. Furthermore the influence of different experimental parameters on the production yield of $Mo(CO)_6$ was investigated, so that the production rate of $Sg(CO)_6$ can be optimized accordingly. Thus, the complete method for a quantitative assessment of the $Sg(CO)_6$ stability is suggested.

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Studies of Flerovium Homologs with Macrocyclic Extractants

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Recent studies of the chemical behavior of copernicium (Cn, element 112) and flerovium (Fl, element 114) together with the discovery of isotopes of these elements with half-lives suitable for chemical studies have spurred a renewed interest in the development of rapid systems designed to study the chemical properties of elements with $Z \geq 114$ [1,2]. Due to the short half-lives of the transactinide elements, fast and efficient separations are necessary to evaluate their properties, such as ionic radii and chemical speciation, by comparing to their lighter homologs. Separations based on macrocyclic extractants show promise for achieving short separation times, large extraction yields, and high separation factors required for transactinide studies.

In this study the potential of different macrocyclic extractants for suitability to a Fl chemical system has been investigated. Crown ethers and their derivatives show high selectivity for metal ions based on their size compared to the cavity of the ether. Di-t-butylcyclohexano-18-crown-6 (Fig. 1) is known to show high affinity for the Pb^{2+} ion.

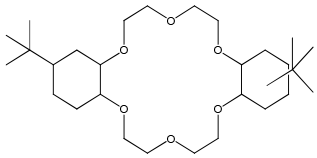

Fig. 1: Di-t-butylcyclohexano-18-crown-6.

Eichrom's commercially available Pb resin is based on the di-t-butylcyclohexano-18-crown-6 extractant sorbed to the resin backbone in isodecanol. Consequently, this resin exhibits high selectivity for Pb^{2+} [3]. Thiacrown ethers, which replace the oxygen atoms with sulfur, act as softer Lewis bases compared to traditional crown ethers [4]. This unique property of thiacrowns should make them even better extractants for softer metals such as Pb. Hexathia-18-crown-6 (Fig. 2) was synthesized and investigated.

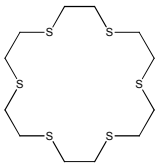

Fig. 2: Hexathia-18-crown-6.

Batch, column and kinetic experiments were performed for the direct homologs and pseudo-homologs of Fl (Pb, Sn and Hg) using the Eichrom Pb resin. The speciation of Pb and Sn were also assessed for the di-t-butylcyclohexano-18-crown-6 extractant. Liquid-liquid extraction studies were performed with the homologs and pseudo-homologs of Fl using hexathia-18-crown-6 in dichloromethane.

References

[1] R. Eichler, et al., Chemical characterization of element 112, Nature, 2007, 447, 72-75.
[2] R. Eichler et al., Indication for a volatile element 114, Radiochim. Acta, 2010, 98, 133-139.
[3] E. P. Horwitz, et al., A lead-selective extraction chromatographic resin and its application to the isolation of lead from geological samples, Analytical Chemica Acta, 1994, 292, 263-273.
[4] E. Sekido, et al., Liquid-liquid extraction of some class b metal ions with thiacrown ether 1,4,8,11-tetrathiacyclotetradecane, Analytical Sciences, 1985, Vol. 1, 363-368.

Acknowledgment: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was funded by the Laboratory Directed Research and Development Program at LLNL under project tracking code 11-ERD-011.

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SHELS - Separator for Heavy ELement Spectroscopy

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The goals of modernization of the VASSILISSA electrostatic separator were to increase the transmission of asymmetric reactions, like ^{22}Ne + ^{238}U or ^{16}O + ^{244}Pu products by factor of 2 - 3 and to extend the region of reactions to be investigated up to symmetric combinations like ^{136}Xe + ^{136}Xe.
For this purpose 3 electrostatic deflectors in the central part of the separator were replaced by combination of two electrostatic and two magnetic deflectors (see Fig. 1). The modernization converted the energy selector VASSILISSA into the velocity filter SHELS.
The new separator will be used together with the detector GABRIELA for spectroscopic studies of heavy isotopes. First tests of the set up were performed with the beams of accelerated ^{22}Ne, ^{40}Ar, ^{48}Ca and ^{50}Ti ions.

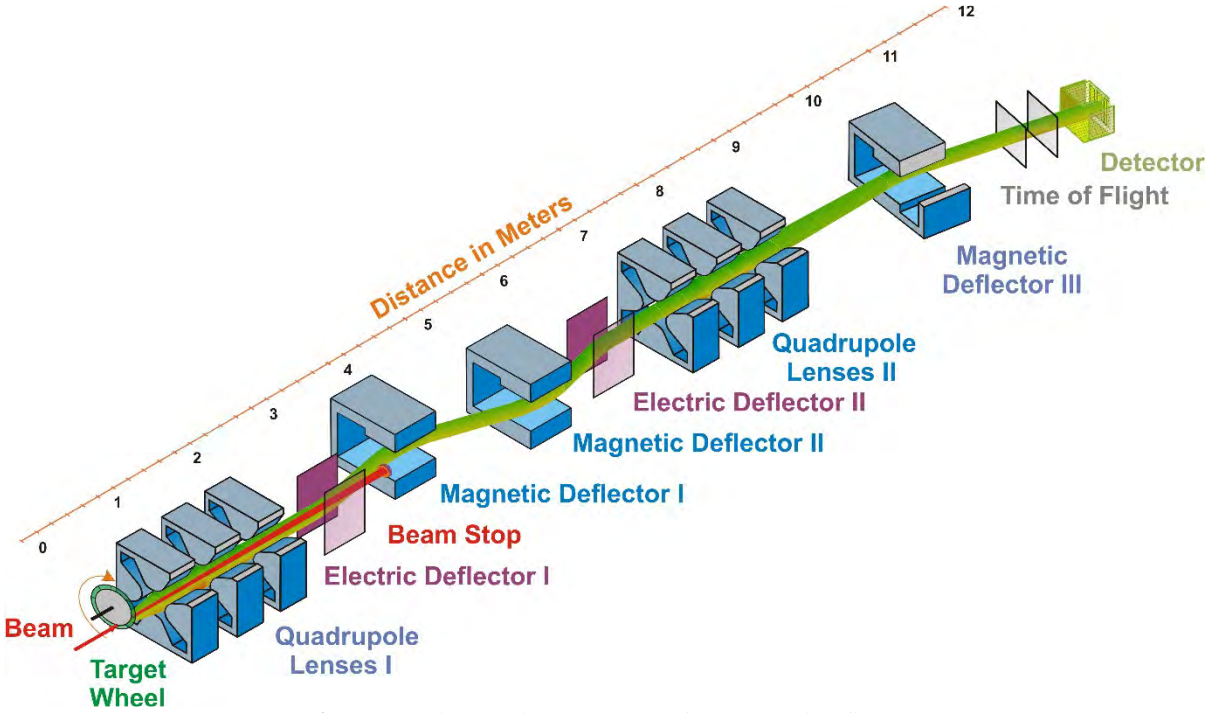

Fig. 1: The ion optical scheme of the velocity filter SHELS

Superheavy elements at GANIL

J. Piot

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GANIL is hosting and will host complementary research programs on superheavy elements using different spectrometers. Experiments are currently run on the LISE spectrometer using the FULIS mode [1] in order to study the level scheme of ^{257}Db in collaboration with GSI.
Future programs include the modification of the large acceptance magnetic spectrometer VAMOS to provide a gas-filled mode. This upgrade, coupled with the presence of the AGATA array at GANIL, fostered several Letters of Intent on the studies of actinides and transactinides nuclei.

The Super-Separator-Spectrometer S3 developed in the framework of the SPIRAL2 project will use the high beam intensities of the LINAG driver to reach nuclei with very low cross-sections and enable new detection techniques for these nuclei. The Physics program for superheavy elements with S3 will focus on three major points : decay spectroscopy of nuclei unreachable with the current installations and reaction mechanism studies using the SIRIUS detection system [2], measurement of the ground states properties with the laser spectroscopy method and production of high purity beams for the DESIR facility [3] through the S3-LEB [4].

References

[1] S. Grévy et al. J. Nucl. Radiochem. Sci. 3 (2002) 9
[2] J. Piot et al. Acta Phys. Pol. B 43 (2012) 285
[3] http://pro.ganil-spiral2.eu/spiral2/instrumentation/desir
[4] R. Ferrer et al. Nucl. Inst. Meth. B 317 (2013) 578

A compact decay spectroscopy set-up for SHN research

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A **Mo**bile **D**ecay **S**pectroscopy detector **S**etup (**MoDSS**) has been developed and constructed to be used for experiments after separation. The compact construction equipped with a standard 150 mm flange can be easily transported and attached to any separator beam line equipped with such a standard flange. It consists of a Si-detector array with a 60 x 60 mm DSSD with 60x60 strips as implantation detector and a box of four 32-strip SSSD detectors in the backward hemisphere. The detector chamber is equipped with four ports for analog signal feed troughs for traditional pre-amplifier signal processing as well as for in-vacuum signal processing, based on the APFEL ASIC, developed first for the PANDA experiment at FAIR. The latter provides Gaussian like signal pulses with 250 ns width and two amplification ranges (1 and 16/32 switchable). A total number of 256 signals can be extracted from the chamber (64 for each port). The chamber provides two cooling circuits. One for the detector cooling which will be operated at -10°C to -15°C, and one for the in-vacuum electronics cooling which will be operated at room temperature.
The set-up is presently at GANIL where first in-beam tests are scheduled for November 2014.

Probing the coexisting shapes at the proton drip line

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During the past decade an extensive program to probe translead nuclei at the proton drip line has been performed in Jyväskylä. In these studies the JUROGAM+RITU+GREAT setup has been utilized. Both in-beam and delayed spectroscopic studies has been performed. On the behalf of my colleagues, I will demonstrate that it is possible to accomplish rather versatile experiments in hard surroundings when a high efficiency separator is combined with state of the art spectrometers in its both ends.

References

[1] J. Uusitalo *et. al.,* PRC 71, 024306 (2005)
[2] K. Andgren *et. al.,* PRC 77, 054303 (2008)
[3] U. Jakobsson *et. al.,* PRC 82, 044302 (2010)
[4] U. Jakobsson *et. al.,* PRC 85, 014309 (2012)
[5] U. Jakobsson *et. al.,* PRC 87, 054320 (2013)
[6] J. Uusitalo *et. al.,* PRC 87, 064304 (2013)
[7] M. Nyman *et. al.,* PRC 88, 054320 (2013)
[8] K. Auranen *et. al.,* PRC 90, 024310 (2014)

STATUS OF THE SC CW-LINAC DEMONSTRATOR PROJECT

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The realisation of the first section of a new superconducting (sc) continuous wave (cw) LINAC is planned in 2015. The project is called “cw LINAC Demonstrator” and is financed by the Helmholtz Institute Mainz (HIM). The aim is a “full performance test” at GSI-HLI of a new 217 MHz sc CH-Cavity which is designed by the Institute of Applied Physics (IAP) of the University Frankfurt.
The kick-off of the Demonstrator project at GSI was in 2010. Meanwhile the design of the key components like the cryostat, solenoids, and the Cavity are finalized and their fabrication comes to the end. In addition the test environment at GSI HLI is about to be completed, so that the commissioning of the sc cw Linac Demonstrator is planned in 2015, when the key components are expected to be delivered.
The future aim, after a successful test of the Demonstrator, is a “full performance test” of the so called “Advanced Demonstrator”, consisting of 5 sc CH-Cavities and 5 sc Solenoids. As test location the GSI HLI is also convenient and would imply a small infrastructural effort. It is planned to realize the project in the POF 3 period until the year 2019.
As an intermediate step a shorter, 8 gaps, 217MHz sc CH-Cavity will be tested in the Demonstrator by swapping one of the Solenoids with this Cavity in 2015.
A three step plan till the realization of the “Advanced Demonstrator” and the status of the Demonstrator project is presented.