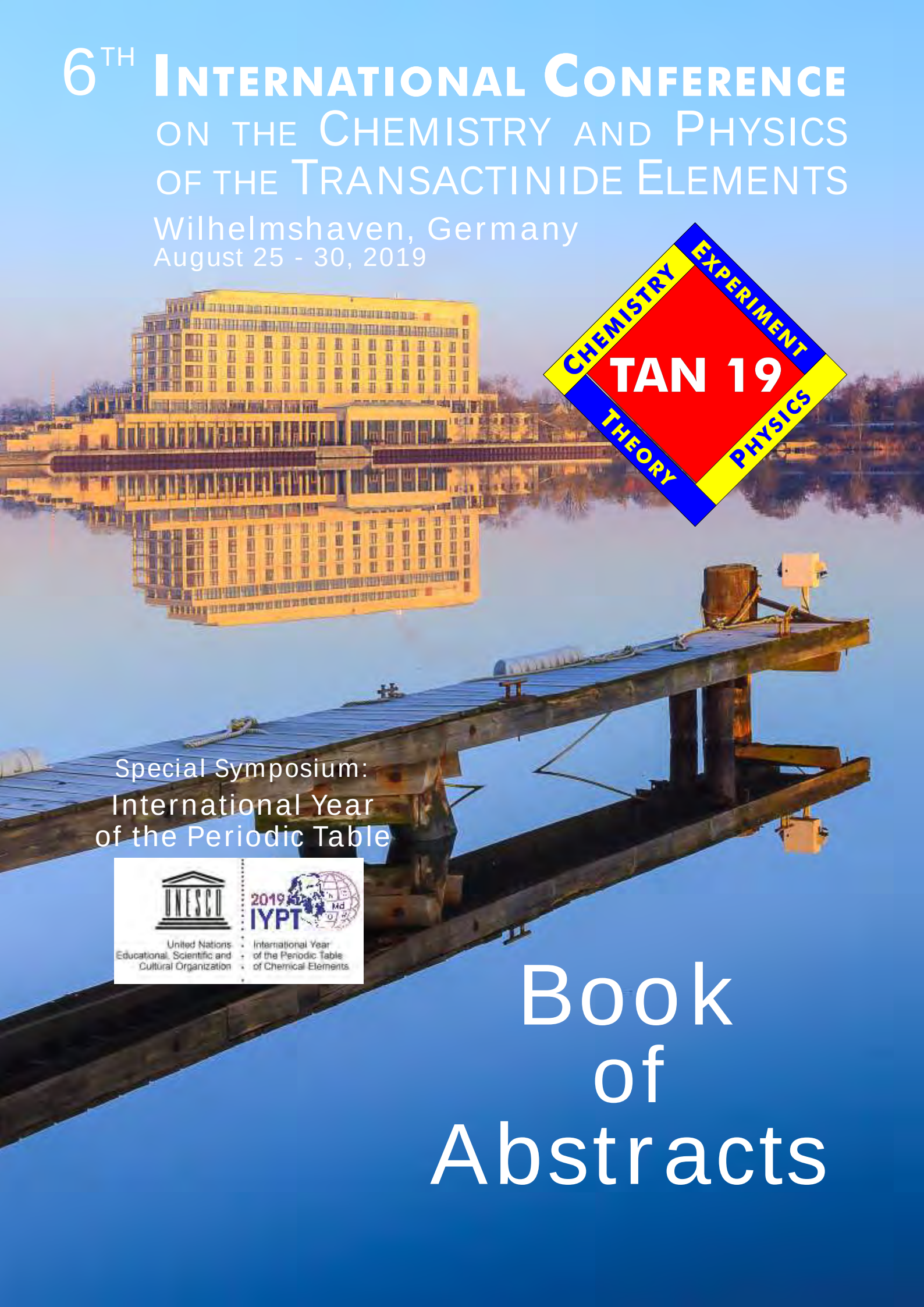
6TH International Conference on the Chemistry and Physics of the Transactinide Elements

Wilhelmshaven, Germany
August 25 - 30, 2019



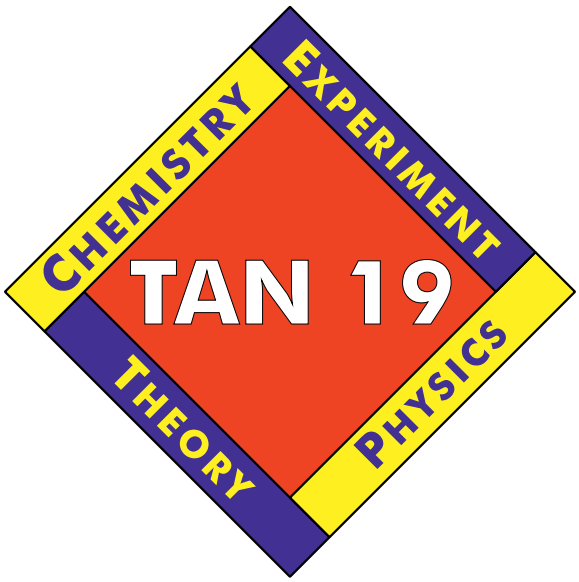
Special Symposium:
International Year
of the Periodic Table

United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

Book of Abstracts

6TH INTERNATIONAL CONFERENCE ON THE CHEMISTRY AND PHYSICS OF THE TRANSACTINIDE ELEMENTS



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The TAN 19 is organized by

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HELMHOLTZ Helmholtz Institute Mainz

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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Time Schedule TAN 19

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			S. Raeder** (ID 105)		A. Yakushev** (ID 39)	
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- **The presenters and the respective type of contribution are noted at the end of each abstract**
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ID 7

Excited states in very heavy elements

SULIGNANO, Barbara; GOIGOUX, Thomas

CEA/Saclay

The search for new magic numbers beyond ^{208}Pb, understanding the enhanced stability of superheavy nuclei (SHN) and their existence despite the repulsive Coulomb interaction is an active field of research in both theoretical and experimental nuclear physics. Precise structure studies of quasi-particle excitations in deformed actinide and transactinide nuclei are crucial to this understanding. In the last decades exhaustive investigations have been carried-out on the decay of deformed nuclei in the transfermium region around ^{254}No, where enhanced stability is observed [1]. Due to quadrupole deformation, these nuclei have Fermi surfaces near orbitals which originate from the non-deformed subshells near the new magic numbers beyond ^{208}Pb and are therefore of great interest in understanding the structure of SHN. Nuclei in this region are produced with cross sections ranging from nb to μb, large enough for decay studies.

In this contribution, I will first report on the investigation of the ^{250}No [2] isotope performed at the Accelerator Laboratory of the University of Jyvaskyla using the RITU gas-filled separator and the GREAT spectrometer. Using fully equipped focal plane detector with digital electronics, we were able to give a definitive answer to the puzzling question concerning the decay path of the isomeric state and the ground state of ^{250}No. During this experiment a dramatic decrease of the ground state half-life compared to neighbouring nuclei has been observed, due to an explicit narrowing of the inner barrier [3]. Those results will be compared to configuration-constrained PES calculations performed for the ^{250}No and other heavy nuclei in the transfermium region [4].

I will, then, describe the new focal plane detection set-up SIRIUS that has been built in the framework of Spiral 2 coupled with the high-intensity stable beams of the superconducting linear accelerator of GANIL, and combined with the new Super Separator Spectrometer S_3. The SIRIUS spectrometer, which has been designed for the identification of fusion-evaporation residue through decay tagging, will provide important information on nuclear deformation, single-particle properties. An outlook on the future experimental campaigns with SIRIUS at S_3, on the very heavy element research, will be also given.

References

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Presenter: GOIGOUX, Thomas (*CEA/Saclay)*

Contribution Type: Contributed Talk

ID 8

Target performance under beam influence: Comparison of different production methods and different incident projectiles

HAAS, Raphael[4]; DÜLLMANN, C.E.[4]; JÄGER, E.[1]; KRIER, J.[1]; LOHSE, S.[2]; RUNKE, J.[1]; YAKUSHEV, A.[1]; BÖHLAND, Sven[2]; KHUYAGBAATAR, J.[1]; MEYER, C.-C.[2]; MOKRY, C.[2]; RENISCH, D.[2]; LOMMEL, B.[1]; KINDLER, B.[1]; POHJALAINEN, I.[3]; MOORE, Iain[3]

[1]GSI, Darmstadt; [2] Inst. für Kernchemie, Johannes Gutenberg-Univ., Mainz; [3] University of Jyväskylä; [4] JGU Mainz / HIM / GSI Darmstadt

With ever increasing beam intensities of new accelerator facilities, the durability of nuclear targets under beam influence becomes more and more critical. Synthesis of the heaviest known elements was achieved using actinide targets. These are frequently produced using the molecular plating technique[1]. After production, fresh targets contain impurities, e.g., organic components. Additionally, the actinides frequently contain crystal water. Therefore, the target layers are quite sensitive to water and oxygen in air and deteriorate during long storage times. To prevent these aging processes, freshly produced targets are usually converted into a long-term stable form. For this, the state-of-the-art relies on a well-established on-line baking-in procedure with heavy-ion beams at low energy. During these irradiations, organic impurities are largely destroyed and the actinide species are converted to oxide species[2]. There is no full understanding of the processes in the target material during baking-in, but the conversions are not just caused by induced heat of the beam[3] and cannot be reproduced by heating up to 700°C in an oxidizing or reducing atmosphere[4]. Several groups are working on the induced effects of swift heavy ion (SHI) irradiation and found, e.g., phase transformations in cubic C-type lanthanide sesquioxides by electronic excitation[5] as well as beam induced electronic sputtering[6]. To obtain a better understanding of the relevant chemical processes and of the performance of Drop-on-Demand printed targets during irradiations with accelerator beams, several irradiations were performed at GSI in Darmstadt and at JYFL in Jyväskylä and the targets were analyzed with different methods. The results of these irradiations will be presented.

References

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Presenter: Mr HAAS, Raphael (JGU Mainz / HIM / GSI Darmstadt)

Contribution Type: Poster

ID 9

Accurate isotope-shift computations for heavy open-shell elements

FRITZSCHE, Stephan, BEERWERTH, Randolf

Helmholtz Institute Jena

During recent years, laser-spectroscopic measurements helped reveal the shape and properties of long chains of short-lived (radioactive) nuclei. Methods, such as the resonant laser ionization and spectroscopy technique, were applied to measure the hyper-fine spectra and isotope shifts along various isotopic chains and to deduce, for instance, information about the shape, size, spin and/or nuclear moments of individual isotopes. For many medium and heavy elements, however, accurate mass- and field-shift factors are required in order to extract such information.

In this talk, I report about recent multi-configuration Dirac-Fock computations for selected medium and heavy elements, including the iron, astatine and actinium chains. Beside of recalling the challenges in performing such computations, we show how correlated and systematically enlarged wave functions help reduce the uncertainties of the theoretical predictions.

Presenter: Prof. FRITZSCHE, Stephan (HI-Jena)

Contribution Type: Invited talk

ID 10

Migration Amount of Metallic Contaminant between Polymeric Patterning Material and Inorganic Substrate with Radioactive Tracer Technique

KO, Fu-Hsiang

National Chiao Tung University

The semiconductor manufacturing of integrating circuit (IC) is one of leading techniques that can achieve nanoscale controlling gate for transistor devices. However, ultratrace metal contamination may cause a distortion of the resultant electrical properties, and may result in failure. Determination of ultratrace elements of patterning materials generally uses the graphite furnace atomic absorption spectrometry. Photoresist ample is digested with the acid mixture in a beaker by a hot plate. However, throughput and contamination are important issues to be questioned with above method. Plasma-based instruments, such as inductively coupled plasma mass spectrometry and inductively coupled plasma optical emission spectrometry, possess the advantage of simultaneous multi-element capability. However, they require a rapid, efficient and reliable sample preparation technology to ensure their efficiency and capability. This is because the plasma-based instruments easily suffer from matrix induced spectral overlap problems and matrix induced signal intensity changes as a consequence of incomplete sample dissolution. In this study, the radioactive tracer technique was proposed to investigate the migration ratios of metal impurities ($^{54}MnCl_2$, 0.838M Bq/g, $t_{1/2}$ = 312d; $^{65}ZnCl_2$, 0.857M Bq/g, $t_{1/2}$ = 244d; $^{137}CsCl$, 0.747M Bq/g, $t_{1/2}$ = 30yr; $^{133}BaCl_2$, 0.778M Bq/g, $t_{1/2}$ = 10.5yr) from polymeric patterning material into the underlying inorganic substrate. The effects of migration temperatures and types of underlying surfaces were also discussed. In addition, possible mechanisms involved in metal migration were proposed to explain the contaminant pathway of various metals associated with their chemical and physical properties.

Contribution Type: Poster

ID 11

Study of Decay properties of $^{269-271}$Hs nucleus formed via Different incoming Channels by using KDE0(v1) Skyrme Force

NIYTI, Niyti[1], DEEP, Aman[2]; SINGH, Raj Pal[1]; KHARAB, Rajesh[2]; CHOPRA, Sahila[3]

[1]Gandhi Memorial National College, Ambala Cantt, Haryana; [2]Kurukshetra University; [3]Panjab University

The method being successfully used for the synthesis of superheavy elements is that of complete fusion reactions, which are classified as cold fusion and hot fusion reactions. In the present work, our earlier study [1] of evaporation residue cross section in the decay of $^{269-271}$Hs* formed in fusion reactions of ^{26}Mg + ^{248}Cm, ^{48}Ca + ^{226}Ra and ^{36}S + ^{238}U at energies E*=30-54 MeV, based on Dynamical Cluster-decay Model (DCM) [2-4], using the pocket formula for nuclear proximity potential is extended to use of other nuclear interaction potentials derived from Skyrme energy density functional (SEDF) based on semi classical extended Thomas Fermi (ETF) approach. We have used KDE0(v1) Skyrme force for our calculation and experimental data is taken from [5]. The calculations are done using a single variable parameter, ΔR, the neck length parameter.

DCM defines the fragments production or CN decay cross section, in terms of ℓ partial waves, as

$$\sigma = \sum_{\ell=0}^{\ell_c} \sigma_\ell = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_c} (2\ell+1) P_0 P; \qquad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}$$

Where P_0 is pre-formation probability, P is penetrability and here $\mu = mA_1A_2/(A_1+A_2)$ is the reduced mass with m as the nucleon mass.

TABLE I: The "Hot fusion" excitation function of 4n evaporation channels from ^{274}Hs* due to entrance channels ^{248}Cm +^{26}Mg, calculated on the DCM for a best fit of ΔR, at different E*=40 MeV energies for KDE0(v1) Skyrme forces, compared with the experimental data [5].

E^*	xn	ΔR(fm) KDE0(v1)	σ_{xn}(nb)	σ_{Exp}(nb)
40	3n	1.4775	1.402.96	$1.39^{1.95}_{-0.89}$
	4n	1.866	2.96	$3^{1.91}_{-1.39}$
	5n	2.1505	0.719	$0.72^{1.56}_{-0.59}$

In the table we have shown our results only for the energy E^*=40 for the t-p combination ^{248}Cm+^{26}Mg . We notice from our results that, though cross sections for the 4n decay channel in three reactions (^{248}Cm+^{26}Mg, ^{236}U+^{38}S and ^{226}Ra+^{48}Ca) are quite different (respectively, 3, 0.8 and 16 pb), ΔR is nearly the same (=1.63±0.1 fm), the small change is due to the spread in E^* from 40 to 50 MeV (not shown here). In other words, the decay process at a fixed E^* occurs at the same relative separation, independent of incoming channel, irrespective of their producing strongly varying cross sections.

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Presenter: Dr NIYTI, Niyti (Gandhi Memorial National College, Ambala Cantt, Haryana, India)

Contribution Type: Poster

ID 12

Vacuum Chromatography on the Long Hard Road to the Accelerator

KRAUS, Benjamin[1,2]; STEINEGGER, Patrick[3]; EICHLER, Robert[1,2]; DRESSLER, Rugard[1]; SATO, Tetsuya K.[4]; TÜRLER, Andreas[2]

[1]Paul Scherrer Institute; [2]University Bern; [3]JINR, Flerov Laboratory of Nuclear Reactions; [4]JAEA

The half-lives of the heaviest element isotopes beginning with moscovium are decreasing with increasing Z from the second to the millisecond range. Therefore, a faster method is needed to investigate these short-lived nuclides, such as vacuum chromatography. In vacuum, the molecular flow regime can be exploited. This regime is governed by the so-called "random walk" as particles move due to adsorption and desorption processes in random directions of straight trajectories without collisional interactions. In comparison to conventional gas chromatography, the speed gain is about an order of magnitude, which would be sufficient to investigate at least some of these short-lived nuclides. Further advantages can be named, such as, controlled chemical states, good alpha spectroscopic resolution, and cleaner chromatographic surfaces. The biggest challenge of vacuum chromatography is its coupling to a SHE production site at a heavy ion accelerator, i.e., to introduce a product recoiling from the nuclear fusion reaction in vacuum into the chromatography. So far, the path of a hot catcher foil (HC) is pursued to rapidly stop the products and immediately release them at thermal energies into the vacuum. Furthermore, a lower chromatographic resolution [1] is expected and a suitable semiconductor material has to be established that can operate in a high-temperature (HT) environment. Although, there are solutions to these problems already, and a proof-of-principle experiment was performed in 2014 [2, 3], there is still need for entirely optimizing the different parts of the setup. For optimizing the chromatographic part, extensive Monte Carlo simulations employing Zvara's microscopic kinetic model [4] have been performed. The setup was modified accordingly. With the optimized geometry of the setup is now suitable for the nuclide Nh-284, which is considered to be in the primary focus for a first transactinide experiment. Another modification concerned the HC where the material was changed from Hf to Ta, as it has better thermal stability. Higher achievable temperatures shall ensure fast solid diffusion and rapid desorption from the surface. For test purposes, the entire IVAC setup was fitted with a Cf-252 source in order to investigate volatile fission products recoiling with high energies from the source. Here, we present the results of the performed measurements and their implications along with other challenges that still need to be faced..

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Presenter: Mr KRAUS, Benjamin (Paul Scherrer Institute / University Bern)

Contribution Type: Poster

ID 14

Laser Resonance Chromatography (LRC): A new methodology in superheavy element research

LAATIAOUI, Mustapha

JGU Mainz / HIM Mainz

Optical spectroscopy constitutes the historical path to accumulate basic knowledge on the atom and its structure. Former work based on fluorescence and resonance ionization spectroscopy enabled identifying optical spectral lines up to element 102, nobelium [1,2]. Beyond nobelium, solely predictions of the atom's structure exist, which in general are far from sufficient to reliably identify atoms from spectral lines. One of the major difficulties in atomic model calculations arise from the complicated interaction between the numerous electrons in atomic shells, which necessitate conducting experiments on such exotic quantum systems. The experiments, however, face the challenging refractory nature of the elements, which lay ahead, coupled with shorter half-lives and decreasing production yields.

In this contribution, a new concept of laser spectroscopy of the superheavy elements is proposed. To overcome the need for detecting fluorescence light or for neutralization of the fusion products, which were employed up to date when lacking tabulated spectral lines, the new concept foresees resonant optical excitations to alter the ratio of ions in excited metastable states to ions in the ground state. The excitation process shall be readily measurable using electronic-state chromatography techniques [3,4] as the ions exhibit distinct ion mobilities at proper conditions and thus drift at different speeds through the apparatus to the detector. The concept offers unparalleled access to laser spectroscopy of many mono-atomic ions across the periodic table of elements, in particular, the transition metals including the high-temperature refractory metals and the elusive superheavy elements like rutherfordium and dubnium at the extremes of nuclear existence.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (No. 819957).

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Contribution Type: Poster

ID 15

Establishment of the volatility trend in Group-5 Elements via gas-chromatographic experiments with Nb-, Ta-, and Db-oxychlorides

CHIERA, Nadine Mariel[1]; SATO, Tetsuya K.[2]; TOMITSUKA, Tomohiro[2]; ASAI, Masato[2]; ITO, Yuta[2]; SHIRAI, Kaori[3]; SUZUKI, Hayato[2]; TOYOSHIMA, Atsushi[2]; TSUKADA, Kazuaki[2]; NAGAME, Yuichiro[2]

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With an expected $[Rn]5f^{14}6d^{3}7s^{2}$ ground state configuration, dubnium (Db, Z = 105) is placed among Group-5 elements, together with vanadium (V, Z = 23), niobium (Nb, Z = 41), and tantalum (Ta, Z = 73). Due to the strong tendency of these transition metals to form stable volatile pentahalide compounds, gas-phase studies with Db were mainly focused on the formation and on the chemical characterization of $DbBr_5$ and $DbCl_5$ complexes. However, in the experiments conducted to-date, discordant results were obtained [1, 2], mostly due to 1) the formation of oxyhalides species with traces of oxygen / water in the carrier-gas, and 2) the modification of the chromatographic surface with aerosol particles used to transport the radionuclides of interest from the production site to the chemical apparatus

In order to shed some light on the chemical behavior of Db in the gas phase, an Isothermal Gas-Chromatographic (IGC) setup - exclusively devoted to study the chemical interaction of oxychloride species with quartz surfaces - was developed at the Japan Atomic Energy Agency (JAEA). In on-line model experiments, the short-lived isotopes 88Nb ($t_{1/2}$ = 14.5 min) and ^{170}Ta ($t_{1/2}$ = 6.76 min) were simultaneously synthesized in the nuclear fusion reactions ^{nat}Ge(^{19}F, xn)^{88}Nb and ^{nat}Gd(^{19}F, xn)^{170}Ta, respectively, at the Tandem Accelerator facility (JAEA). The nuclear reaction products were swept out from the recoil chamber and directly injected into a heated quartz column (1000 °C) by the inert carrier gas. There, oxychloride compounds were synthesized by addition of $SOCl_2$ and O_2, and successively transported along the isothermal chromatographic column by the gas flow. The compounds leaving the chromatographic column were attached to KCl aerosol particles and transported to the collection and detection system. The yields of $NbOCl_3$ and $TaOCl_3$ passing through the quartz chromatographic column as a function of the applied isothermal temperature (range: 200-600 °C) were recorded. The chromatographic behavior of $NbOCl_3$ and $TaOCl_3$ was analyzed with a Monte-Carlo simulation method based on an adsorption-desorption kinetic model. Adsorption enthalpy values (ΔH_{ads}) on quartz at zero surface coverage of $\Delta H_{ads}(NbOCl_3)$ = 102 ± 4 kJ/mol and $\Delta H_{ads}(TaOCl_3)$ = 128 ± 5 kJ/mol were deduced [3]. The experimental ΔH_{ads} values were successively related to the macroscopic standard sublimation enthalpy, $\Delta H°_{subl}$, as a measure of the volatility of each substance, by applying an empirical correlation between ΔH_{ads} and $\Delta H°_{subl}$ for metal-oxychlorides. The inferred sublimation enthalpies are in agreement with tabulated thermochemical values.

Under the same experimental conditions, the formation of a volatile dubnium oxychloride species at temperatures above 400°C was observed. For the purpose, ^{262}Db ($t_{1/2}$ = 34 s) was synthesized in the nuclear fusion reaction ^{248}Cm(^{19}F, 5n)^{262}Db at the Tandem Accelerator facility. The future chemical exploration of $DbOCl_3$ in the temperature range 200-400 °C with the IGC setup will provide a final assessment on the relative volatility of Group-5 oxychlorides.

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Presenter: Dr CHIERA, Nadine Mariel (Paul Scherrer Institute)

Contribution Type: Contributed talk

ID 18

A new gas-jet setup for laser spectroscopy of superheavy elements

NOTHHELFER, Steven[1]; BLOCK, Michael[1,2,3]; FERRER, Rafael[4]; KRON, Tobias[3]; RAEDER, Sebastian[2]; SCHNEIDER, Fabian[3]; VAN DUPPEN, Piet[4]; VERSTRAELEN, Elise[4]

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Experimental data on the hyperfine structure in superheavy elements (SHE) is important to obtain valuable information about their nuclear structure. In addition, the atomic properties of SHE are of special interest because they are difficult to predict by theoretical calculations due to strong relativistic effects. Therefore, a new gas-jet experiment is being developed, which aims to enable precise investigation of electronic states of rare atoms with the use of laser spectroscopy in a supersonic gas-jet. The study of SHE is realized by stopping fusion evaporation residues in a buffer gas cell after their production and separation at SHIP at GSI, Darmstadt. Subsequently, the fusion evaporation residues are transferred into a supersonic gas-jet, which is produced by a de Laval-nozzle. Laser spectroscopy in this jet enables a higher resolution compared to the previous RADRIS setup, resulting in spectral linewidths of few hundred MHz, granting access to valuable information on nuclear moments and spins which can be derived from the hyperfine structure and isotope shifts. This talk will summarize the current status of the experiment together with first results.

Presenter: Mr NOTHHELFER, Steven (Helmholtz-Institut Mainz)

Contribution Type: Poster

ID 19

Priority experiments at the SHE Factory

OGANESSIAN, Yuri; DMITRIEV, Sergey; UTYONKOV, Vladimir

Joint Institute for Nuclear Reactions, Dubna

At present, the region of known superheavy nuclei (SHN) with Z≤118 and their α-decay descendants forms a relatively narrow "ridge" in the nuclear landscape. In order to more fully understand the role of shell stabilization in this region, it is essential to considerably extend the area of synthesized SHN; this requires a significant increase in the overall sensitivity of experiment. In the beginning of 2019, a new experimental complex, the SHE Factory at FLNR, including a high-current cyclotron DC280 and a gas-filled separator DGFRS-2, is planned to be commissioned. The project of priority experiments which are planned at DGFRS-2 will be presented. These include study of the ^{243}Am+^{48}Ca reaction for measurement of yields of Mc isotopes with large statistics at different beam energies. The production of elements Cn and Fl in the ^{242}Pu+^{48}Ca reaction with use of the chemistry setup placed behind DGFRS-2 and investigation of their chemical properties is discussed as well. The search for the heaviest isotopes of Og in the reactions of a mixed Cf target with ^{48}Ca projectiles can be performed with use of the new target which is under preparation at ORNL. The ^{244}Pu+^{50}Ti reaction, leading to known isotopes of Lv, could shed light on the level of the cross sections of the reactions of actinide target nuclei with ^{50}Ti. The experiments aimed at the synthesis of new elements 119 and 120 in the reactions of ^{249}Bk and $^{249\text{-}251}$Cf with ^{50}Ti will be also considered.

Presenter: UTYONKOV, Vladimir (Joint Institute for Nuclear Reactions)

Contribution Type: Invited talk

ID 20

Enhanced ion thermalization with the cryogenic buffer-gas stopping cell of SHIPTRAP

KALEJA, Oliver[1,2,3]; ANĐELIC, Brankica[4,5,6]; BLAUM, Klaus[1]; BLOCK, Michael[2,3,4]; CHHETRI, Premaditya[6,3]; DROESE, Christian[7]; DÜLLMANN, Christoph E.[2,3,4]; EIBACH, Martin[7,3]; ELISEEV, Sergey[1]; EVEN, Julia[5]; GÖTZ, Stefan[2,4,3]; KALANTAR–NAYESTANAKI, Nasser[5]; LAATIAOUI, Mustapha[2,4]; MISTRY, Andrew[3,4]; MINAYA-RAMIREZ, Enrique[8]; MURBÖCK, Tobias[4,3]; SCHWEIKHARD, Lutz[7]; THIROLF, Peter G.[9]; RAEDER, Sebastian[3,4]; GIACOPPO, Francesca[3,4]

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The existence of the heaviest elements is crucially connected to nuclear shell effects, which counteract spontaneous fission and determine the stability of such exotic systems. Penning-Trap Mass Spectrometry (PTMS) is a suitable technique, which allows the investigation of shell effects and their evolution for nuclear systems with different proton to neutron ratios through direct and highly-precise measurements of the atomic masses and the nuclear binding energies.

During summer 2018 direct mass measurements of transfermium nuclides ^{251}No (Z=102), ^{254}Lr (Z=103) as well as the superheavy nuclide ^{257}Rf (Z=104) have been successfully achieved, for the first time, with the SHIPTRAP mass spectrometer. Such challenging experiments face the problem of very low production rates, down to few ions per day and demand a very efficient ion preparation and manipulation together with high detection sensitivity and resolving power. In particular, prior to their transfer to the Penning traps, the ions need to be thermalized after their production via fusion-evaporation reactions and separated by the velocity filter SHIP. This step is the most crucial and it is achieved by slowing down the ions in a buffer-gas stopping cell. In this contribution the latest optimizations of the recently implemented SHIPTRAP cryogenic buffer-gas stopping cell and its enhanced performance in terms of efficiency and purity will be presented.

Presenter: KALEJA, Oliver (MPIK Heidelberg, JGU Mainz, GSI Darmstadt)

Contribution Type: Poster

ID 22

The complicated, challenging configuration structure of the 5g elements

DYALL, Kenneth

Schrodinger, Inc

Determining the configuration structure of the 5g elements and identifying the ground states is an extremely challenging problem. The configuration structure is complicated because there are five shells being filled at the same time: 5g, 6f, 7d, 8s, and 8p, and the spin-orbit splitting is large enough that the configurations must be considered in *jj* coupling, i.e. $5g_{7/2}$ and $5g_{9/2}$, $6f_{5/2}$, and so on. The computational challenge is enormous because there can be millions of states generated for a single configuration, and there are large relaxation effects associated with changes in the 5g occupation.

This presentation reports progress towards identifying ground configurations and ground states of the elements from Z=125 to Z=145, which covers the range of elements in which the 5g shell is being filled. A number of previous works have used density functional theory, but owing to the huge number of states generated by these configurations and the importance of both relaxation and nondynamic correlation, wave function methods are necessary to make the identifications. Here, calculations are performed on a large number of single configurations of the neutral atoms and ions to explore the configuration structure. The Dirac-Hartree-Fock and CI methods are used with the Dirac-Coulomb Hamiltonian, as implemented in the 4-component atomic structure codes GRASP and RAMCI.

The main findings so far are: (1) The ground states have 3-4 valence electrons (8s, 8p, 7d) at the low end of the range, increasing to 6 at the high end. (2) The lowest configurations have a given number (n) of electrons distributed between the 5g and 6f core orbitals, with typically 2 or 3 in the 6f and n-2 or n-3 in the 5g.

Contribution Type: Contributed talk

ID 23

Direct mass measurement of low-lying isomers in the heaviest elements with SHIPTRAP

GIACOPPO, Francesca[1,2]; ANĐELIĆ, Brankica[2,3]; BLAUM, Klaus[4]; BLOCK, Michael[5,2,1]; CHENMAREV, Stanislav[2,6]; CHHETRI, Premaditya[12,1]; DROESE, Christian[7]; DÜLLMANN, Christoph E.[5,2,1]; EIBACH, Martin[1,7]; ELISEEV, Sergey[4]; EVEN, Julia[3]; GÖTZ, Stefan[5,2,1]; GUTIÉRREZ, Manuel J.[8]; HERFURTH, Frank[1]; HEßBERGER, Fritz P.[1,2]; KALANTAR-NAYESTANAKI, Nasser[3]; KALEJA, Oliver[4,5,1]; KHUYAGBAATA, Jadambaa[1,2]; VAN DE LAAR, Jacques J. W.[5,2]; LAATIAOUI, Mustapha[5,2]; LOHSE, Steffen[5,2]; MARTYNOVA, Natalia[6,9]; MINAYA-RAMIREZ, Enrique[10]; MISTRY, Andrew[1,12]; MURBÖCK, Tobias[2,1]; NOVIKOV, Yuri[6,9]; RAEDER, Sebastian[1,2]; RODRIGUEZ, Daniel[8]; SCHNEIDER, Fabian[5,2]; SCHWEIKHARD, Lutz[7]; THIROLF, Peter G.[11]; YAKUSHEV, Alexander[1,2]; FILIANIN, Pavel[4]

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A comprehensive understanding of the heaviest elements requires detailed studies of the quantum mechanical nuclear shell effects which determine regions of enhanced shell stabilization and allow the very own existence of such heavy nuclides as bound systems. Investigations of the nuclear structure evolution for different proton to neutron ratios around the deformed neutron shell gap at N=152 are ongoing by applying Penning-Trap Mass Spectrometry (PTMS) with the SHIPTRAP setup. Such investigations at the upper limit of the nuclear chart will provide information for a better understanding of the nature of the underlying strong interaction and will help to constrain predictions for the location of the next spherical shell closures, expected by different models at Z=114∼126, N=184.

In a successful experimental campaign in summer 2018, we exploited the novel Phase-Imaging Ion Cyclotron Resonance technique (PI-ICR) [1] with the relocated SHIPTRAP mass spectrometer [2] to resolve, for the first time, low-lying isomeric states in ^{251}No (Z=102) and ^{254,255}Lr (Z=103) isotopes. In addition the direct mass measurement of ^{251}No, ^{254}Lr as well as of the superheavy element ^{257}Rf (Z=104) was achieved for the first time. Furthermore the masses of ^{254}No and ^{256}Lr were determined with unprecedented precision.

In this talk an overview of the recent results will be presented. A summary of the latest optimization of the SHIPTRAP setup and its enhanced performances will be included.

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Presenter: Dr GIACOPPO, Francesca (GSI Darmstadt, HIM Mainz)

Contribution Type: Contributed talk

ID 24

Supersonic gas jets for high-resolution laser Ionization Spectroscopy of Heavy Elements

FERRER, Rafael

KU Leuven - IKS
for the S3-leb Collaboration (LPC-IPNO-GANIL-JOGU-JYFL-IRFU-IPHC)

Resonant laser ionization and spectroscopy are widely used techniques at radioactive ion beam facilities to produce pure beams of exotic nuclei and measure the shape, size, spin and electromagnetic multipole moments of these nuclei. In such measurements, however, it is difficult to combine a high efficiency with a high spectral resolution. A significant improvement in the spectral resolution by more than one order of magnitude has recently been demonstrated without loss in efficiency [1] by performing laser ionization spectroscopy of actinium isotopes in a supersonic gas jet, a new spectroscopic method [2] that is suited for high-precision studies of the ground- and isomeric-state properties of nuclei located at the extremes of stability. Spatial constraints and limitations of the pumping system in the present setup prevented a high quality jet formation and, as a consequence, an optimal spatial and temporal laser-atom overlap. Offline characterization studies at the In-Gas Laser Ionization and Spectroscopy (IGLIS) laboratory at KU Leuven [3] are being carried to overcome these limitations in future experiments when dedicated IGLIS setups at new generation radioactive beam facilities become operational [4]. These studies also include the characterization of the flow dynamics and the formation of supersonic jets produced by different gas-cell exit nozzles using the Planar Laser Induced Fluorescence (PLIF) technique on copper isotopes, the test of new gas-cell designs with better transport and extraction characteristics and the characterization of a high-power, high-repetition rate laser system. Extrapolation of the online results on the actinium isotopes show that the performance of the technique under optimum conditions can reach a final spectral resolution of about 100 MHz (FWHM) and an overall efficiency of 10% when applied in the actinide region. In this presentation I will summarize a number of on-line results and mainly will focus on the characterization studies and future prospects of the in-gas-jet resonance ionization method applied on very-heavy elements.

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Presenter: Dr FERRER, Rafael (KU Leuven - IKS)

Contribution Type: Poster

ID 27

Towards the Ion Mobility Measurement of Actinides and Transactinides

RICKERT, Elisabeth[1,2]; BLOCK, Michael[1,2,3]; BACKE, Hartmut[2]; DÜLLMANN, Christoph E.[1,2,3]; LAATIAOUI, Mustapha[1,2]; LAUTH, Werner[2]; RAEDER, Sebastian[3]; SCHNEIDER, Fabian[2]; SCHNEIDER, Jonas[2]

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Ion mobility spectrometry (IMS) is a powerful tool to investigate ion-atom interaction potentials. The sensitivity of ion mobilities to the electronic configuration has been proven for various elements across the periodic table. For heavy elements in particular, the impact of relativistic effects on the electronic configuration may lead to deviations in the periodicity, hence to distinct ion mobilities. This opens up a new niche for isobaric purification and element identification in the research of actinides and transactinides. Systematic IMS measurements across the lanthanides [1] are being extended to the actinides and transactinides. At first the actinide elements from Pu (Z=94) to Cf (Z=98) will be studied for which drastic changes in the electronic configurations were predicted [2] and the experiments can be performed offline. Afterwards IMS measurements will be extended to the transactinides, which have to be produced online at an accelerator facility such as the GSI in Darmstadt. The IMS apparatus to be utilized consists of a gas-filled drift chamber and a differential pumping section, containing a radiofrequency-quadrupole ion guide and a quadrupole mass filter (QMS) for mass-selective ion detection. The ion production differs depending on the natural abundance of the sample. For offline studies, ions are produced from primed filaments by laser resonance ionization, for online experiments, the ions are injected into the drift chamber of the apparatus through thin entrance window foil. Ions traverse the drift chamber, before they are extracted through a nozzle and mass selected by the QMS. Different electronic configurations of the sample ion results in different ion-neutral interaction potentials and collision cross sections and hence in distinct ion mobilities. In this poster, the experimental approach, the first results, and the future plans are presented.

References

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Presenter: RICKERT, Elisabeth (HIM/JGU Mainz)

Contribution Type: Poster

ID 28

Improving the laser ablation ion source at SHIPTRAP

ANĐELIĆ, Brankica[1,2]; BLAUM, Klaus[3]; CHHETRI, Premaditya[1,5,6]; DORRER, Holger[1,4]; DÜLLMANN, Christoph E.[1,4,5]; EVEN, Julia[2]; GIACOPPO, Francesca[5,1]; KALANTAR-NAYESTANAKY, Nasser[2]; KALEJA, Oliver[3,4,5]; MURBÖCK, Tobias[1,5]; RAEDER, Sebastian[1,5]; SCHNEIDER, Fabian[4,1]

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The mass of a nuclide is a fundamental property that provides information about the nuclear binding energy. It is thus crucial for nuclear structure studies, in particular in the region of transactinide nuclides where nuclear shell effects determine their stability and their existence itself. Penning-trap mass spectrometry is a powerful tool for direct and precise mass measurements and it does not require a detailed knowledge of the nuclear level schemes. It is complementary to decay spectroscopy studies and it allows improving the accuracy of masses determined by decay energies up to the region of the superheavy elements.

The Penning-trap mass spectrometer SHIPTRAP includes a laser ablation ion source that provides reference ions for such mass measurements. In addition, it allows mass measurements of long-lived actinide isotopes. To increase the sensitivity for rare isotopes, the laser ablation, ionization as well as transport and injection of the ions into the Penning traps have to be efficient. Therefore, a gas-filled miniature Radio-Frequency Quadrupole (mini-RFQ) [1] was recently implemented in the SHIPTRAP laser-ablation source to thermalize the laser-ablated ions and collect them in a narrow bunch.

In order to further improve the laser ablation ion source, additional design optimization and simulation studies are ongoing. The current effort aims at enabling the efficient preparation of short ion bunches from target samples containing well below one microgram of material. In this contribution an overview of the present status and planned upgrades of the laser ion source will be presented.

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Presenter: ANĐELIĆ, Brankica (HIM Mainz & KVI-CART, RU Groningen)

Contribution Type: Poster

ID 29

Actinide-Targets produced with a Drop-on-Demand printing system

RENISCH, Dennis[1,2]; DÜLLMANN, Christoph E.[1,2,3]; EBERHARDT, Klaus[1]; HAAS, Raphael[1,2,3]; LOHSE, Steffen[1]; MEYER, Carl-Christian[1,2]; RUNKE, Jörg[1,3]; THÖRLE-POSPIECH, Petra[1,2]; LOMMEL, Bettina[3]; KINDLER, Birgit[3]

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Actinide and lanthanide targets with specific requirements regarding thickness, homogeneity, chemical purity and mechanical stability are essential for a broad range of physical and chemical experiments, including the production of transactinides and their lighter homologs in heavy-ion induced fusion reactions. A novel target preparation method, combining a nanoliter dispenser with an x-y-translation stage, was developed and implemented recently at the Institute of Nuclear Chemistry of the Johannes Gutenberg-University Mainz [1]. This so-called "Drop-on-Demand" (DoD-) system can handle aqueous as well as organic solvents and is applicable to all kinds of substrates, including metal, polymer, or carbon foils. The wetting of the surface, which affects the size of the deposit after evaporation of the drop, depends on properties of the substrate like hydrophobicity and roughness, as well as on the viscosity and surface tension of the solution. By choosing appropriate conditions, it is possible to achieve from single drops deposits that cover an area with a diameter as low as 300 µm. By depositing large numbers of drops, large-area targets of areas up to a few cm² can be produced. Analytics of the produced layers was performed using scanning electron microscopy, radiographic imaging, as well as alpha- and gamma-spectroscopy.

Examples of ongoing and future experiments where DoD-targets are in use include studies of the exotic Th-229m isomer via the p + Th-232 reaction at JYFL, Cf-252 fission fragment sources for JRC Geel, muonic atoms spectroscopy of Ra-226 and Cm-248 at PSI [2], or Ho-163 samples for high-precision mass measurements with PENTATRAP for the ECHo collaboration [3]. First steps on the study of the performance of DoD-targets under beam influence online [4] and offline [5] have been taken.

The advantages of the DoD-method in these cases, compared to targets prepared by other methods like molecular plating [6], and their relevance for superheavy element research will be described.

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Presenter: Dr RENISCH, Dennis (JGU Mainz / HIM)

Contribution Type: Contributed talk

ID 30

High-precision calculations of ionization potentials, spectra, electromagnetic transition amplitudes and isotope shifts in No, Db, Sg, Bh, Hs, Mt and Og atoms.

FLAMBAUM, Victor; DZUBA, Vladimir; LACKENBY, Bryce

University of New South Wales

Most of superheavy elements (SHE) have more than 4 electrons in open shells and can not be accurately calculated using conventional methods. We developed a high precision approach [1,2] efficient for such atoms and demonstrated its high accuracy by comparison of the calculated and measured values for lighter analogues. The spectra and electromagnetic amplitudes in Sg, Bh, Hs, Mt have been calculated for the first time [3], for other SHE new levels and E1-amplitudes have been accurately calculated [2,4-6]. The accuracy of the ionisation potential calculations has been significantly improved [2-6].

An interesting feature of SHE is a very large spin-orbit interaction which makes subshells for the orbitals with the fixed total angular momentum of electron j. This effect replaces Hund's rule for lighter elements. The difference in the trends is clearly seen on the graphs of the ionization potentials I(N) as functions of number of d-electrons N in the open shell [3]. Position of the ionization potential maxima in SHE corresponds to the filled d3/2 subshell with four d-electrons while in the lighter atoms and ions the maximum of I(N) correspond to the half-filled shells with five d-electrons (Hund's rule). In SHE this is position of the minimum of I(N).

Large relativistic effects also contract the spectrum of the open-shell SHE compared to their lighter analogues. This is advantageous as it results in a large number of the strong electromagnetic transitions in the optical region and therefore increases the likelihood of the future detection of these transitions.

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Presenter: Mr LACKENBY, Bryce (University of New South Wales)

Contribution Type: Contributed talk

ID 31

Calculation of isotope shifts in superheavy elements and search for nuclear island of stability

FLAMBAUM, Victor; DZUBA[1], Vladimir; VIATKINA, Anna[2]; GEDDES, Amy[1]; LACKENBY, Bryce[1]

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We performed analytical [1,2] and many body calculations [3-8] of the isotope shifts (IS) in superheavy elements (SHE). IS is needed to find differences of nuclear charge radii and test nuclear models. Another motivation is based on a possible existence of a hypothetical island of stability with the "magic" neutron number N=184. Optical lines of many actinide atoms and ions up to Z=99 have been possibly found in the spectra of the Przybylski's star. These elements may be products of decay of meta-stable nuclei belonging to the island of stability [1].

SHE nuclei produced in laboratory are neutron-deficient and highly unstable. More stable neutron-reach nuclei may be produced during the neutron star merger. In this case there may be a chance to see atomic and ionic spectra of more stable neutron-rich isotopes in astrophysical data. To predict these spectra one should measure atomic spectra of the neutron-deficient isotopes in laboratory and add to them the calculated isotope shifts [1].

In Ref. [2] we derived analytical formula for IS suitable for superheavy elements (SHE). Works [3-8] contain relativistic many-body calculations. IS for No, Db, Sg, Bh, Hs, Mt and Og have been calculated in [4-8] using a new method [8,9] which allows us to perform accurate relativistic many-body calculations in atoms with a large number of electrons in an open shell.

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Presenter: Ms VIATKINA, Anna (J. Gutenberg University, Mainz)

Contribution Type: Contributed talk

ID 32

Exploration of Nuclear Structure and Decay Properties Neutron Deficient Dubnium, Rutherfordium and Lawrencium Isotopes

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GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

To understand the fundamental interactions is a basic topic in natural science. In this quest the limits of nuclear stability are regions of specific relevance. Among them superheavy nuclei are of particular interest as they owe their existence due to a delicate interplay of short range nuclear forces acting between the nucleons (protons and neutrons) and long-range Coulomb forces acting solely between charged particles, i.e. the protons. In this sense understanding nuclear stability and its limits at the upper part of the charts of nuclei ($Z > 100$) is essential to understand basic interactions. As the stability of a nucleus is strongly correlated to its decay properties and its structure, understanding of the latter in heaviest nuclei is presently - besides synthesizing new elements - the main challenge of experimental and theoretical investigations concerning the field of superheavy elements (SHE). At GSI Darmstadt an extensive program on investigating decay properties and nuclear structure investigations by means of studying α – and EC – decay, spontaneous fission as well as α-γ – or α – conversion electron (CE) spectroscopy of nuclei collected in the focal plane of the velocity filter SHIP has been started about two decades ago. The project covered both: systematic investigations of single particle levels populated by α-decay or electron capture (EC) decay in odd-mass isotopes, decay properties of even-even and odd-odd nuclei, as well as investigation of two- or four-quasi-particle states forming K isomers. In this contribution we will report on the results of recent α- and EC decay studies of Db-258, Rf-257,258, and Lr-254,257 [1,2,3]. New isomeric states in Db-258, Rf-258, Lr-254,257, and Md-250 were identified, first partial decay schemes and tentative spin and parity assignments of ground states and isomeric states in Db-258, 7Lr-254,257 were established, the decay scheme of Rf-257 was improved. Recently interest on a possible production of SHE via pxn – deexcitation channels arose. In an early SHIP – experiment a cross-section of 100 pb was reported for the reaction Bi-209(Ti-50,p)Rf-258. In this sense we reanalyzed all fusion – evaporation data taken for the reaction Ti-50 + Bi-209 at SHIP. The results obtained for the pn- channel will be reported.

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Contribution Type: Contributed talk

ID 33

On-line Gas-Filled Separator GFS-2 for the Dubna Superheavy Element Factory

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Joint Institute for Nuclear Research

Production cross sections of superheavy elements (SHE) with Z = 112 ÷ 118 are in the range of a few picobarns or less. To get access to heavier nuclides and carry out the detailed study on their properties, a sufficient increase in the beam intensity and the development of a separator providing the necessary background suppression are needed. This is the main goal of the construction of a first-ever SHE factory based on the high-current heavy-ion cyclotron DC280 and the new GFS-2 at the Flerov Laboratory of Nuclear Reactions. The separator comprises the Q1-D30-Q2-Q3-D10 ion optical scheme.The quadrupole Q1 focuses EVRs in the vertical direction. The dipole magnet D30 with a deflection angle of 30 degrees and a gap of 120 mm focuses the particles by the rotated rear pole face in the horizontal direction. The Q2 and Q3 quadrupoles focus ERs on the focal plane detector. The dipole D10 with a deflection angle of 10 degrees reduces the background from elastically scattered gas atoms, i.e., hydrogen (protons) or helium (alpha-particles). The separator was manufactured by SigmaPhi (Vannes, France) and installed at the beam line No. 3 of the cyclotron DC280 in an experimental hall designed in compliance with class II radiation safety requirements for work with high-active targets made of transuranium isotopes. During the first stage of testing of the properties of the separator, the detection and data acquisition systems were studied using the reactions Ar+Dy, O+Pb, and Ca+Pb. Tests will continue using the Ca+Pu and Ca+Am thick targets. Several hundred decay events of Fl and Mc isotopes are expected to be recorded. After completion of these tests, it is planned to start the synthesis of new superheavy elements with Z=119 and 120.

Contribution Type: Poster

ID 34

Alpha decay properties of the semi-magic nucleus ^{219}Np

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Synthesis of neutron-deficient actinide nuclei close to the N=126 shell closure is of importance to understand the stability of the N=126 closed shell and to predict the limit of existence of nuclei in this region. To study ^{219}Np, the experiment of ^{187}Re(^{36}Ar,4n)^{219}Np was carried out at the gas-filled recoil separator SHANS and the beam of ^{36}Ar was delivered by the sector focusing cyclotron of HIRFL in Lanzhou, China. The incident beam energy was 191.5 MeV and the beam intensities were 300-400 pnA. The targets consisted of 380μg/cm^2 thick layers of ^{187}Re, which were evaporated on 45μg/cm^2 thick carbon foils. The targets with the backing upstream were mounted on a stationary frame.
After amplified with preamplifiers, signals of all detectors were processed in a digital data acquisition system. Sixteen 14-bits waveform digitizers V1724 with 100 MHz sampling frequency developed by CAEN were used to record samples of the input signals and transfer them to FPGA (Field Programmable Gate Array) for real-time digital signal processing. Prior to the application of digital algorithms in the offline digital signal processing, a correlation among events from both ends of silicon strips, back of PSSDs, side detectors and MWPCs was made based on time stamps. The events from different detectors that can be correlated within the setting time windows were written into one entry. In order to facilitate searching for α-decay chains in the next time, all entries were arranged in chronological order. For each trace correlated in one entry, the first 200 samples were used for baseline calculation. After subtracting the baseline, the two traces from the top and bottom of the silicon strip were added up as a complete trace taking into account the amplification factors of the preamplifiers. Then each complete trace with 1500 samples was analyzed by using a digital leading-edge discriminator and the trapezoidal algorithm to extract the time and the amplitude information respectively.

The reaction products were identified using spatial and time correlations between the implants and subsequent α decays. According to the observed α-decay chain, an alpha-particle energy of E_α=9039(40) keV and a half-life of $T_{1/2}=0.15^{-0.07}_{+0.72}$ ms were determined for ^{219}Np. The deduced proton binding energy of -301(83) keV fits well into the systematics, which gives another evidence of that there is no sub-shell closure at Z=92. Negative value of proton binding energy indicates that ^{219}Np is a semi-magic nucleus beyond the proton drip-line. In addition, the influence of the N=126 shell closure on the stability of Np isotopes was also discussed within the framework of α-decay reduced widths.

Contribution Type: Poster

ID 36

Estimation of synthesizing new superheavy elements using dynamical model

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Kindai University

Experiments on the synthesis of superheavy elements using heavy ion collisions have recently been successful in finding several new elements, and the known area in the nuclear chart is approaching the 'Island of Stability' step by step. In order to success the synthesis of superheavy elements, it is indispensable to clarify the fusion-fission mechanism, which is included a role of the nuclear structure of colliding nuclei and the deformation of them in the fusion process. For this purpose, a large amount of experimental data is available, including the mass and total kinetic energy distribution of fission fragments, excitation function of each cross section, mass-angle distributions and so on. Using such experimental data, we verify of the model and establish a reliable model to describe the fusion-fission process. To describe heavy-ion fusion reactions around the Coulomb barrier with an actinide target nucleus, we propose a model which combines the coupled-channels approach and a fluctuation-dissipation model for dynamical calculations. Fusion-fission, quasi-fission and deep quasi-fission are separated as different Langevin trajectories on the potential energy surface. Also, we develop the dynamical model to apply the transfer reaction and estimate the probability to produce new superheavy nuclei. Moreover, we estimate the mass distribution of fission fragments of the compound nuclei. We calculate the mass-angle distribution of the fragments in the reaction, and investigate the fusion-fission or quasi-fission process in heavy and superheavy mass region. The fusion-fission mechanism of the process is discussed.

Contribution Type: Contributed talk

ID 38

Noli turbare circulos meos: Julius Lothar Meyer (1830-1895), Dmitri Ivanovič Mendeleev (1834-1907) and the Periodic System of Elements

BOECK, Gisela

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Although the phrase "don't disturb my circles" is attributed to Archimedes, Julius Lothar Meyer admitted in 1880 that he also uttered it while reading Dmitri Ivanovič Mendeleev's 1869 paper on the Natural System of Elements. Meyer and Mendeleev – contemporaries and counterparts forging a path to our periodic system?

When we look at the logo of the International Year of the Periodic Table of Chemical Elements published by the United Nations General Assembly and UNESCO, we see only the face of Mendeleev. A closer examination of Mendeleev's and Meyer's biographies reveals that they worked on the same problem in the 1860s and each published several papers on element systems. Both men attended the Karlsruhe conference, both were writing textbooks and contemplating in which order elements should be introduced. Numerous other scholars, such as Alexandre-Émile Béguyer de Chancourtois, John Newlands, William Odling, and Gustavus Hinrichs, were also working to classify the elements. This leads us to ask: why is it Mendeleev's work we hold in such high regard? An answer may be found in the papers of Meyer, Mendeleev, and these other scholars.

This talk compares their works under the aspects of how they referred to periodicity, if they predicted new elements, and how they themselves evaluated their own input to the periodic system. The development of different displays of the system, including two- and three-dimensional presentations, is also discussed. Finally, the results of a study about the reception of the Periodic system in textbooks and in popular writings will be presented.

Contribution Type: Invited talk for the symposium

ID 39

Chemical studies of superheavy elements at a recoil separator, with a focus on Fl

A. Yakushev[1,2], L. Lens[1,3], Ch.E. Düllmann[1,2,3], M. Asai[4], M. Block[1,2,3], H. Brand[1], H.M. David[1], J. Despotopulos[5], A. Di Nitto[1,3], K. Eberhardt[2,3], U. Forsberg[6], P. Golubev[6], M. Götz[1,2,3], S. Götz[1,2,3], H. Haba[7], L. Harkness-Brennan[8], W. Hartmann[1], R.-D. Herzberg[8], D. Hinde[9], J. Hoffmann[1], A. Hübner[1], E. Jäger[1], M. Jourdan[3], D. Judson[8], J. Khuyagbaatar[1,2], B. Kindler[1], Y. Komori[7], J. Konki[10], J.V. Kratz[3], J.Krier[1], N. Kurz[1], M. Laatiaoui[1,2], S. Lahiri[11], B. Lommel[1], M. Maiti[12], A. Mistry[1,2], Ch. Mokry[2,3], K. Moody[5], Y. Nagame[4], J.P. Omtvedt[13], P. Papadakis[10], V. Pershina[1], T. Reich[3], D. Rudolph[6], J. Runke[1,3], L. Samiento[6], T.K. Sato[4], M. Schädel[1], P. Scharrer[1,2,3], B. Schausten[1], D. Shaughnessy[5], J. Steiner[1], P. Thörle-Pospiech[2,3], A. Toyoshima[4], N. Trautmann[3], K. Tsukada[4], J. Uusitalo[11], K.-O. Voss[1], A. Ward[8], M. Wegrzecki[14], N. Wiehl[2,3], E. Williams[9], V. Yakusheva[1,2]

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For the past ten years, flerovium has been in the focus of chemical studies, yet its chemical character is not clear. Results obtained at FLNR Dubna [1] and at GSI [2] were interpreted to point at a noble-gas-like and a metallic character, respectively. In the course to settling the question, the safe identification of its nuclear decay chains has proven difficult [3]. As was demonstrated [2; 4], the coupling of chemistry setups to an electromagnetic separator provides the necessary suppression of the primary beam and of the products of multi-nucleon transfer reactions, and thus a gain in sensitivity for the unambiguous identification of single atoms of the heaviest elements. This facilitates studies of chemical properties and even of the exploration of nuclear properties of superheavy elements in chemistry experiments [5]. The gas filled separator TASCA has been used and continuously upgraded as a preseparator for such experiments during the last decade. The current focus of the superheavy element chemistry experiments behind TASCA is on flerovium and nihonium [6]. Recent molecular, cluster, and solid-state relativistic calculations on Cn, Nh, and Fl suggest these elements to be the most inert in their groups. However, they are still expected to form bonds of substantial strength with metals like Au [7,8]. Several experimental campaigns on the study of Fl were carried out at TASCA, which resulted in the observation of eight Fl atoms. The gas-solid interaction with quartz and Au surfaces was studied, in which the atoms first passed a quartz surface kept at room temperature, then a Au surface kept at room temperature, and finally a progressively colder Au surface that reached temperatures as low as -160°C. The final analysis of the results is ongoing, and the interaction mechanism of Fl with the Au surface will be discussed at the conference. This allows settling the question of the chemical nature of Fl.

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Presenter: Dr YAKUSHEV, Alexander (GSI, Darmstadt)

Contribution Type: Invited talk

ID 41

Status report of the TRIGA-TRAP experiment

VAN DE LAAR, Jacques J.W.[1,2]; BLAUM, Klaus[3]; BLOCK, Michael[1,2,4]; DÜLLMANN, Christoph E.[1,2,4]; LOHSE, Steffen[1,2]; SCHNEIDER, Fabian[1,2]; NAGY, Szilard[3]; CHENMAREV, Stanislav[1,2,5]

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Superheavy elements exist exclusively because of quantum-mechanical shell effects. With increasing proton number the Coulomb repulsion increases rapidly and these shell effects gain in importance for heavy nuclei, as they can increase the nuclear lifetimes by many orders of magnitude. The effect is most pronounced in the vicinity of shell closures. One of the relevant shell closures was identified at $N = 152$. Signatures for shell closures include a sudden drop in the two-neutron separation energy S_{2n}. This can experimentally be determined by high-precision measurements of the masses of nuclides in the vicinity of the shell closure. The TRIGA-TRAP experiment is a double Penning-trap mass spectrometer used to perform high-precision mass measurements of long-lived transuranium isotopes and short-lived fission-products at the research reactor TRIGA Mainz. It thus ideally complements the on-line capabilities of the SHIPTRAP setup at GSI Darmstadt. Prompted by a recent recharge of the TRIGA-TRAP superconducting magnet, the experimental setup was upgraded and recommissioned. Currently, measurements to investigate systematic effects are ongoing. A measurement campaign of several transuranium isotopes is planned for the next months. The status, latest results, and an outlook for the TRIGA-TRAP facility will be presented.

Presenter: Mr VAN DE LAAR, Jacques J. W. (Inst. für Kernchemie, Johannes Gutenberg-Univ. Mainz; HIM Mainz)

Contribution Type: Poster

ID 42

Structure of superheavy nuclei

NAZAREWICZ, Witold

Michigan State University

In 2016, four new elements were added to the periodic table of chemical elements: nihonium, moscovium, tennessine and oganesson. These elements define the current upper limits of mass and atomic numbers. According to theory, due to their large atomic numbers, the new arrivals are expected to be qualitatively and quantitatively different from lighter species. The questions pertaining to superheavy nuclei are in the forefront of research in nuclear physics and neighboring areas [1,2]. This talk will offer a broad perspective on the field.

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Contribution Type: Invited talk

ID 43

Optimization of Transactinide Carbonyl Complex Formation and Transport using Fission Products from Cf-252

WITTWER, Yves; EICHLER, Robert; TÜRLER, Andreas

Paul Scherrer Institute, Villingen

In 2014, the first synthesis of $Sg(CO)_6$ suggested the investigation of various superheavy elements (SHEs) in the form of their metal carbonyl complexes. [1] However, following campaigns targeted at investigating the thermodynamic properties of this new compound were seriously harmed by very low chemically yields for metal carbonyl complexes in general, ranging from about 5-10% for $Sg(CO)_6$ and $W(CO)_6$ to 20% for $Mo(CO)_6$. This does not only raise the question if efficient experiments using $Sg(CO)_6$ will be feasible, but also if an extension to heavier SHEs than Sg will be possible in the near future.

This work is dealing with improving the chemical and transportation yield for carbonyl complexes produced under single-atom chemistry conditions in general. To allow the investigation of various reaction parameters while still resembling an actual SHE experimental setup in its principles, a model system was constructed. In this system, the spontaneous fission of ^{252}Cf is used to generate short lived single atomic elements Mo, Tc, Ru and Rh which are recoiling into a reaction chamber that is flushed with a gas mixture containing CO. Depending on the reaction conditions applied, $Mo(CO)_6$, $Tc(CO)_n$, $Ru(CO)_5$, and $Rh(CO)_m$ complexes are synthesized more or less efficiently, serving as models for Sg, Bh, Hs, and Mt carbonyl complexes respectively. Those complexes are volatile enough to be transported through a PFA-capillary to a charcoal trap, where they are adsorbed and quantified using gamma-spectroscopy. From this quantification, the overall efficiency of the system under the applied and pretty much controlled reaction conditions can be estimated. The system can be operated continuously and its performance appears to resemble the one of an actual SHE-setup operated under similar conditions.

Using this setup, we investigated the effects of various reaction parameters including pressure, gas flow, temperature, used gas mixture, various impurities and the effect of different purification columns used for gas purification and their stability over time. To our surprise, it was found that especially the last parameter plays an important role in the successful formation/transportation of metal carbonyl compounds, the reason for this being currently investigated. Assuming that an extrapolation from the model to the actual SHE-system is possible, our measurements suggest that the investigation of Sg and Hs carbonyl complexes should be possible with high to very high yields. The investigation of $Bh(CO)_n$ and $Mt(CO)_m$ is expected to be more challenging but also not impossible.

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Presenter: Mr WITTWER, Yves (Paul Scherrer Institute)

Contribution Type: Contributed talk

ID 45

Electronic structure, bonding and volatility of carbonyl compounds of Tc, Re, and Bh

ILIAS, Miroslav (*Matej Bel Univ., Banská Bystrica; GSI, Darmstadt*)
PERSHINA, Valeria (*GSI, Darmstadt*)

Molecular properties of $M(CO)_5$ and $MH(CO)_5$, where M = Tc, Re, and Bh, and of the products of their decomposition, $M(CO)_4$ and $MH(CO)_4$, were calculated using Density Functional Theory and Coupled-Cluster methods implemented in the relativistic quantum chemistry program suits such as ADF, DIRAC and ReSpect [1].

The predicted first M-CO bond dissociation energies (FBDE) of $M(CO)_5$ and $MH(CO)_5$ turned out to be significantly weaker than those of the corresponding Re homologs. The reason for that is the relativistic destabilization and expansion of the 6d AOs, responsible for weaker sigma-forth and pi-back donations in the Bh compounds. The relativistic FBDEs of $M(CO)_5$ have, therefore, a lambda-shape behavior in the row Tc-Re-Bh, while the non-relativistic values increase towards Bh.

Using results of the molecular calculations and a molecule-slab interaction model, adsorption enthalpies, Hads, of group-7 carbonyl closed-shell hydrides on quartz and Teflon were estimated for future gas-phase chromatography experiments. It was found out that $BhH(CO)_5$ should be almost as volatile as the homologs, however, its interaction with the surfaces should be somewhat stronger than that of $MH(CO)_5$ (M = Tc and Re), while the $M(CO)_4$ (M = Tc, Re, and Bh) molecules should be non-volatile. It will, therefore, be difficult to distinguish between group-7 $MH(CO)_5$ species by measuring their Hads on surfaces of Teflon and quartz with an error bar of ± 4 kJ/mol. Likewise the trends in properties and Hads of group-7 carbonyl hydrides are similar to those of group-8 carbonyls of Ru, Os and Hs.

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Presenter: ILIAS, Miroslav (Matej Bel Univ., Banská Bystrica; GSI, Darmstadt)

Contribution Type: Invited talk

ID 46

Alpha Decay and Fission of Isomers

CLARK, Roderick

LBNL

While the single-particle structure is vital to understanding the stability of the heaviest elements, the alpha decay and fission processes ultimately determine how long a nucleus will survive. Observations in the decay chains of ^{270}Ds [1,2] suggest that high-K isomeric states can decay via alpha emission where the metastable state is longer lived than the ground state of the same nucleus. Such results have tremendous implications for how far we may be able to push the experimental studies of the heaviest elements.

In this contribution I describe recent efforts to gain a better understanding of alpha decay of metastable states in the heavy nuclei. In particular, the Superfluid Tunneling Model [3] has been used to reproduce the alpha decay properties of the high-K isomers in ^{270}Ds and ^{266}Hs, including the unusual competition between $L \approx 10$ and $L \approx 0$ alpha transitions seen for the K—isomer in ^{270}Ds [4]. The model has also been used to examine the alpha-decay fine structure of isomers in other regions, including the high-spin isomers in N=84 isotones [5] as well as the evolution of alpha particle preformation across the nuclear landscape.

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Contribution Type: Contributed talk

ID 48

Periodic Trends in Superheavy Elements

SCHWERDTFEGER, Peter; MEWES, Jan; SMITS, Odile

Massey University, Auckland

In the last decade we have seen the production of new elements for the Periodic Table up to nuclear charge 118. How far can we go? Where does the Periodic Table end and can we place the elements correctly in the Periodic Table? What chemistry can we do with such exotic elements? What is the chemical and physical behavior of these exotic elements, and do we have to go beyond non-relativistic quantum mechanics to understand them? Recent developments in relativistic quantum theory have made it possible to obtain accurate electronic properties for the trans-actinide elements with the aim to predict their chemical and physical behavior. Changes in periodic trends due to relativistic effects are outlined for the superheavy elements with nuclear charge Z>111. First-principles relativistic quantum simulations at ambient conditions show that Cn is a liquid with a narrow temperature range to the gas phase, whilst Og shows a rather unusual behavior being a semi-conductor and a solid.

Presenter: Prof. SCHWERDTFEGER, Peter (Massey University)

Contribution Type: Invited talk

ID 49

A Prototype On-line System for Alpha-Spectrometry in Aqueous Solution

KRUPP, Dominik; SCHERER, Ulrich, W.

HS Mannheim

Due to the short half-lifes of the known transactinide isotopes, further investigation of the physical and chemical properties of this isotopes can only be performed in on-line experiments, immediately after their production [1], [2]. Different types of on-line detection systems were developed for this purpose, e.g. the COMPACT detector system for chemical gas-solid adsorption studies of the heaviest known elements and their lighter homologs [3] or the liquid-liquid extraction based system SISAK, with subsequent LSC measurements [4]. To perform aqueous chemistry experiments also fast separations systems were developed utilizing e.g. ion exchange chromatography e.g. ARCA II [5] but their use has been discontinued due to the relatively long time required for sample separation before detection. The aim of this project is to compensate for the disadvantages of the technique by performing chemical separation from solution directly on an alpha-detector [6]. In order to allow selective enrichment of the desired chemical species, an extraction agent is bonded to the detector surface. Based on this measurement setup, the well-known radiochemical separation techniques [7] can be done in on-line experiments directly on the surface of an alpha detector even for very short-lived radionuclides. The acquired decay data are analyzed by a self-developed Matlab-application. This program converts the raw data into an energy- and time-resolved spectrum, with an additional alpha-alpha-correlation function. Data from off-line experiments will be presented. This innovation could grant access to experiments, which are currently not possible with the established detection systems e.g. exploring chemical properties of super-heavy elements.

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Presenter: Mr KRUPP, Dominik (HS Mannheim)

Contribution Type: Poster

ID 50

Speeding up gas-phase chemistry to access elements beyond Fl

GÖTZ, Stefan [1,2]; BLOCK, Michael[1,2,3]; DÜLLMANN, Christoph E.[1,2,3]; FOLDEN III, Charles[4]; GLENNON, Kevin[4]; GÖTZ, Michael[1,2,3]; JÄGER, Egon[3]; KALEJA, Oliver[5,3,2]; KINDLER, Birgit[3]; KRIER, Jörg[3]; LENS, Lotte[3]; LOMMEL, Bettina[3]; MISTRY, Andrew[3]; RAEDER, Sebastian[3]; TERESHATOV, Evgeny[4]; VOLIA, Merry[4]; YAKUSHEV, Alexander[3]; YAKUSHEVA, Vera[3]

[1]HIM Mainz; [2]Johannes Gutenberg-Univ. Mainz; [3]GSI Darmstadt; [4]Cyclotron Institute, Texas A&M University; [5]MPIK Heidelberg

Since the first isothermal gas chromatography studies of rutherfordium (Rf, Z = 104), gas-phase separation procedures have grown in importance for studies of the SuperHeavy Elements (SHE) and allow for elucidating the influence of relativistic effects on their chemical properties [1, 2]. The heaviest elements, whose chemical properties have been reproducibly studied with gas-chromatography methods, are copernicium (Cn, Z = 112) and flerovium (Fl, Z = 114). Due to the low production rates and short half-lives, T1/2, only single atoms are available in chemical experiments. Nevertheless, the required sensitivity can be achieved, best by combining chemical setups with electromagnetic pre-separators [3,4]. The most time-consuming step in the experiments performed with the current TASCA-COMPACT setup as it was used for the Fl experiments is the thermalization of the fusion-evaporation reaction products in the recoil transfer chamber and their transport to COMPACT. Gas chromatographic techniques are currently applicable to isotopes with half-lives longer than about 0.5 seconds. Besides Cn and Fl, also Nh is in reach with this technique. Looking at elements beyond Fl, however, the extraction time of typically at least 0.5 s is significantly longer than typical half-lives of readily accessible isotopes. For Mc, for example, this is ^{288}Mc with $T_{1/2}$ = 170 ms [5]. To overcome this limitation, exploratory experiments on the coupling of COMPACT to an existing buffer gas cell operating with electric fields [6,7] were carried out.

In this contribution the latest optimisations of the recently implemented MiniCOMPACT and its enhanced performance for extraction of non-volatile ions and an overview of the recent on-line measurements at GSI Darmstadt and Texas A&M University, College Station, will be given.

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Presenter: Mr GÖTZ, Stefan (HIM Mainz, Johannes Gutenberg-Univ. Mainz, GSI Darmstadt)

Contribution Type: Poster

ID 51

Hindered decays of heaviest high-K isomers

JACHIMOWICZ, Piotr[1]; KOWAL, Michał[2]; SKALSKI, Janusz[2]

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A possibility of superheavy (SH) high-K isomers living longer than the respective ground states makes a search for candidates for such states very interesting. Finding sufficiently long-lived SH isomers could open new possibilities for studies of chemical properties on SH isomeric states rather than on ground states.

I will present results of our search for candidates for long-lived high-K isomers in even-even and odd-A superheavy nuclei. Our analysis is performed within the microscopic-macroscopic approach, based on the deformed Woods-Saxon single-particle potential [1] and the Yukawa-plus-exponential macroscopic energy [2]. Parameters of the model, well tested during many years in the region of the heaviest nuclei, are kept unchanged. We consider two-, three- and four-quasiparticle configurations; their energy is found by a standard blocking procedure and the subsequent minimization over deformations.

As suggested by the fission hindrance of odd-A nuclei, one may expect a fission hindrance also for high-K isomers. The crucial questions are: 1) whether a candidate would be a real isomer (in the sense of a hindered EM decay) and 2) whether a hindrance of alpha decay relative to the ground state may be expected. The question 1) is nearly impossible to answer in the present state of the theory – hence one has to select candidates for the exceptionally low-lying, high-K configurations. The exact calculations of alpha-decay rates are also not yet available. Therefore we try to pay special attention to possible hindrance mechanisms in the alpha decay process. We consider the following: a structural (K) hindrance (as estimated by others) of transitions with a big change in the K quantum number, and the coexisting energetic hindrance: when a stucture-preserving transition has a significantly reduced (as compared to the ground state to ground state one) Q-alpha value (and hence a significantly smaller decay rate).

For some candidate low-lying configurations we estimate alpha half-lives of the order of seconds. This concerns selected Ds isotopes for which we have found a quite strong hindrance against alpha decay which mainly results (contrary to what was so far suggested in the literature) from the structure of the two-quasi-proton excitation [3].

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Presenter: Dr JACHIMOWICZ, Piotr (Institute of Physics, University of Zielona Góra)

Contribution Type: Contributed talk

ID 52

Element Genesis over 13.8 billion Universal years

EN'YO, Hideto

RIKEN Nishina Center

Since the Big Bang, 13.8 billion years have passed. Trillions of shining stars, neutron stars and black holes were born, exploded and merged. These years are the history to create heavier elements, molecular, materials and stars, by confining energy into them, firstly with the Higgs mechanism, then with weak, strong and electromagnetic forces, and finally with gravitational force. Has the Universe ever created nihonium or other super heavy elements? Probably no. Our journey in searching heavier elements has already entering the region in which even the Universe has never explored yet. In the presentation the 13.8 billion years of element genesis is looked back together with 100 years of Japanese element searches to reach nihonium. Finally our recent effort is mentioned to enter the 8th row of the periodic table, which will be a small step for us, but one giant leap for mankind.

Contribution Type: Invited talk for the symposium

ID 53

In-situ synthesis of volatile transition metal carbonyl complexes with short-lived radioisotopes

GÖTZ, Michael[1,2,3]; DÜLLMANN, Christoph E.[3,1,2]; YAKUSHEV, Alexander[3]; ASAI, Masato[4]; BALLOF, Jochen[2,5]; DI NITTO, Antonio[6,7]; EBERHARDT, Klaus[2,1]; GÖTZ, Stefan[1,2,3]; HABA, Hiromitsu[8]; JÄGER, Egon[3]; KANEYA, Yusuke[4]; KOMORI, Yukiko[8]; KRATZ, Jens-Volker[2]; KRIER, Jörg[3]; LOMMEL, Bettina[3]; MITSUKAI, Akina[4]; NAGAME, Yuichiro[4]; SATO, Tetsuya K.[4]; TOYOSHIMA, Atsushi[4]; TSUKADA, Kazuaki[4]; WOLTER, Vanessa[2]; YAKUSHEVA, Vera[3]

[1]HIM Mainz; [2]Univ. Mainz; [3]GSI, Darmstadt; [4]JAEA; [5]CERN; [6]Univ. Naples; [7]INFN Naples; [8]RIKEN

Chemical investigations of superheavy elements (SHE) are of broad interest, as relativistic effects, which scale with Z2, are predicted to strongly influence the chemical behavior of these elements [1]. Comparative studies of the transactinides with their lighter homologs help to understand the influence of relativity on the electron shell. However, due to experimental limitations only a few compounds of the superheavy elements have been studied so far. Recently, carbonyl complexes became accessible as a novel SHE compound class: the Sg hexacarbonyl was synthesized and studied five years ago [2]. The bonding in carbonyl complexes emerges from electron pair donation from the CO molecules surrounding the central atom into its empty d orbitals and subsequent π-back bonding [3]. As superheavy elements are produced in heavy ion induced fusion reactions employing high beam intensities, the method of physical preseparation was applied to avoid interaction of the beam with the carbon monoxide ligand and the carbonyl complexes. However, the fusion products from the asymmetric heavy-ion reactions as needed for the carbonyl studies with Sg, Bh, and Hs, suffer from a low transmission through recoil separators. In case of TASCA or GARIS [4], the efficiencies are in the order of 13% for Sg. Due to a significant reduction of the production cross sections beyond Sg, more efficient approaches are called for to approach Bh and heavier transactinides. We thus started exploring the possibilities for chemical investigation of the metal carbonyl complexes of SHE without using a preseparation stage, which would avoid the corresponding losses of almost 90%. For this, we developed a setup using two separate chambers for (i) thermalization of the fusion products, and (ii) chemical synthesis of carbonyl complexes. Beam is only present in the first of those chambers, and the fusion products are transferred to the second chamber by pure inert gas flow. We performed experiments with the 4d elements (i) with a Cm-248 fission fragment source to study the efficiency of the transfer into the second chamber, and (ii) with fission products from the U-235(n,f) reaction at the research reactor TRIGA Mainz to optimize the overall efficiency of the technique. In further experiments at the JAEA Tandem-Accelerator, the synthesis of Os, W and Re carbonyl complexes was demonstrated. The carrier noble gas and the carbon monoxide were pre-cleaned by passing gas purification cartridges. Volatile fusion products and the fusion products forming volatile carbonyl complexes with CO were transported with the gas stream to a chemistry laboratory. Here the products were trapped on a charcoal filter and the γ-lines of the decaying isotopes were identified. The recent results from the latest online experiments will be presented at the conference.

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Presenter: Mr GÖTZ, Michael (HIM, Univ. Mainz, GSI)

Contribution Type: Poster

ID 54

Alpha-decay studies on the most neutron-deficient U isotopes near the N=126 shell closure

ZHANG, Zhiyuan

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Alpha decay, as a pervasive decay mode of unstable heavy nuclei, plays a crucial role in the identification of new superheavy elements and investigation on nuclear structure of exotic nuclei near the proton drip line. In the vicinity of the doubly magic nucleus ^{208}Pb, alpha-decay study provides an opportunity to disclose the intriguing nature of nuclear structure moving away from the closed shells. Recently, we performed a series of experiments on the gas-filled recoil separator SHANS (IMP, Lanzhou) aimed at the alpha-decay studies of new isotopes near the mass region of N=126 shell closure, especially for the most neutron-deficient U isotopes.

In this presentation, the present status of our setup, the new decay data on 2^{14}U and more accurate data on ^{216}U will be presented. Based on these measurements, the new systematics for the decay energies, half-lives and reduced alpha-decay widths on the U isotopes will be established. The possible influences on the stability of the N=126 shell closure in U isotopes will be discussed.

Contribution Type: Poster

ID 56

Desorption studies for laser spectroscopy of the heavy elements

CHHETRI, Premaditya[1,2,3]; BLOCK, Michael[2,3,4]; GIACOPPO, Francesca[2,3]; KALEJA, Oliver[5,4,3]; LAATIAOUI, Mustapha[4,2]; MURBÖCK, Tobias[2,3]; NOTHHELFER, Steven[2,4]; RICKERT, Elisabeth[2,4]; SCHNEIDER, Fabian[4]; RAEDER, Sebastian[2,4]

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Laser spectroscopic investigations on the heaviest elements gives access to fundamental atomic and nuclear properties. Relativistic and QED effects as well as electron correlation strongly influence the atomic shell. These effects lead to a change in the electronic configuration along chemical homologues. A precise determination of atomic energy levels or the first ionization potential will help to unambiguously characterize the atomic ground state and validate atomic modeling across the periodic table. To probe the atomic shell structure of the actinides and transactinides with Z >100, ultra-sensitive spectroscopy techniques have been developed and optimized for online applications. One such technique is the RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) that was recently applied to nobelium (No, Z=102). After production in fusion-evaporation reactions the recoil ions were separated from the primary beam by the velocity filter SHIP, stopped in a buffer-gas cell and collected onto a filament. A subsequent thermal evaporation as neutral atoms enabled probing the atomic structure using laser resonance ionization. The created photo-ions were transported to a silicon detector and identified by their characteristic alpha-decay energy.

To extend the application of this technique to heavier elements, for example lawrencium (Lr, Z=103), the release of the captured recoils from the filament has to be studied in detail. In the experiments on nobelium, a tantalum filament was used for neutralization and evaporation, but first tests indicated that an elevated release temperature is needed for Lr. In combination with a relatively lower first ionization potential, this results in an elevated background form surface ions, which hampers the total sensitivity of the technique. The desorption enthalpy and the filament work function crucially determine in this respect the evaporation efficiency and the background created by surface ions, respectively.

In this contribution, a setup for mass separated detection of surface ionized and laser ionized lanthanides evaporated from different filaments is presented. The desorption of ytterbium (Yb, Z=70) and lutetium (Lu, Z=71) from different surface materials will be discussed with regard to the prospects its of laser-spectroscopic investigations.

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Presenter: Dr CHHETRI, Premaditya (TU Darmstadt, HI Mainz, GSI)

Contribution Type: Poster

ID 57

Superheavy Element Cn & Fl - Chalcogen Interactions Using Gas Chromatography

IONESCU, Paul[1]; EICHLER, Robert[1]; TÜRLER, Andreas[2]; KRAUS, Benjamin[1,2]; WITTWER, Yves Jean-Jacques[1,2]; DRESSLER, Rugard[1]

[1]PSI; [2]Universität Bern

The discovery of superheavy elements (Z > 104) has long piqued interest in their chemistry and properties, especially in comparison to their group homologues. Due to short half-lives of these synthetic elements produced in the lab, the preferred method of analysis is gas chromatography as it is fast and highly sensitive. Fl (Z = 114) and decay product Cn (Z = 112) are investigated due to their adequate half-lives. Both elements are expected to exhibit inert, volatile behavior. On-line gas-chromatography of Cn in the past hinted at an unexpected affinity of the superheavy element with trigonal Se, however insufficient data was collected to provide conclusive results. An extended experimental campaign in 2018 using the reaction ^{242}Pu(^{48}Ca, 3n)^{287}Fl(α) → ^{283}Cn designed to reproduce these results yielded mixed results, with two events tentatively assigned to ^{283}Cn observed on Se at 15°C, and four others on Au-covered detectors. No events attributed to Fl were recorded. In parallel, short-lived Hg isotopes were produced simultaneously to monitor the chromatography. The Hg indicated accumulation of gas contaminants over time resulting in a significantly decreased detection rate. However, this was only observable on the Au detectors, since the interaction of Hg with Se is of purely physisorption character. The results from this campaign will be presented for the first time along with plans for future experiments at the new SHE-factory in Dubna, Russia behind the gas-filled separator in hopes of increasing SHE yield and addressing the impurity problem.

Presenter: Mr IONESCU, Paul (PSI)

Contribution Type: Poster

ID 59

Nuclear Spectroscopy along ^{287,289}Fl decay chains

SÅMARK-ROTH, Anton; RUDOLPH, Dirk; COX, Daniel; SARMIENTO, Luis

Lund University

In recent years the search for heavier and heavier elements has been undertaken predominantly through the exploitation of 48Ca-induced fusion-evaporation reactions on actinide targets. These superheavy elements have all been identified through correlated α-decay chains terminating in spontaneous fission. Due to advances in detection technology, data processing, and various data analysis tools for superheavy element studies it has been possible to perform the first multi-coincidence high-resolution spectroscopy experiments along these decay chains, namely studying moscovium decays with TASISpec.

The desire for even Z-odd N experimental anchor points at the proposed magic proton number Z = 114 (Fl) to constrain and guide nuclear structure theory has led to an experiment being performed at GSI via the reaction ^{48}Ca + ^{242,244}Pu, employing high-resolution α-photon coincidence spectroscopy, to study the decay chains of ^{287,289}Fl.

The upgraded version of the TASISpec decay station, including the eventual Lundium station, will be described, along with this the earliest experimental results will be presented.

Presenter: Mr SÅMARK-ROTH, Anton (Lund University)

Contribution Type: Contributed talk

ID 61

A multi-reflection time-of-flight mass analyzer for SHANS at IMP/CAS

TIAN, Yulin; HUANG, Wenxue; WANG, Yongsheng; WANG, Junying; GAN, Zaiguo; ZHOU, Xiaohong; XU, Hushan

Institute of Modern Physics, Chinese Academy of Sciences

Accurate mass data of transuranium nuclei are particularly important for the study of superheavy nuclei and the investigation of 'islands of stability'. A low energy mass spectrometry to provide high-precision mass measurement and isobaric separation of short-lived fusion-evaporation reaction products is being under construction at Spectrometer for Heavy Atom and Nuclear Structure (SHANS). A multi-reflection time-of-flight (MRTOF) mass analyzer for SHANS has been designed, constructed and tested [1].

A set of computer programs, in which the ion trajectories are simulated by SIMION and the parameters are varied and optimized by a Nelder-Mead simplex algorithm both in the mirror switching mode and in-trap-lift mode, has been developed for understanding of ion motion kinematics in an MRTOF mass analyzer and finding out parameter sets as starting points for the test of device in laboratory. In the in-trap-lift mode, the latest optimization results by using SIMION give a maximal mass resolving power of 160,000 for a TOF of 6.4 ms and 130,000 in the mirror switching mode [1,2,3].

The preliminary test results by applying the simulated voltages show that its mass resolving power has reached ~7,000 for a TOF of 1.6 ms [1], and the latest test results will be reported.

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Presenter: Dr TIAN, Yulin (Institute of Modern Physics, Chinese Academy of Sciences)

Contribution Type: Poster

ID 62

Isothermal gas chromatography of chloride of Zr and Hf at off-line experiment for the gas-phase investigation of Rf

SHIRAI, Kaori[1]; GOTO, Shin'ichi[1]; OOE, Kazuhiro[2]; KUDO, Hisaaki[1]

[1]Niigata University; [2]Osaka University

To clarify chemical properies of element 104, Rf, gas chromatographic behaviors of chlorides Rf and its homologs, Zr and Hf, have been studied at tracer-scale [1]. However, the values of adsorption enthalpy ($\Delta_{ads}H$) for quartz column and relation of $\Delta_{ads}H$ among group-4 elements are different in each report. Therefore, it is difficult to discuss volatility of $RfCl_4$ quantitatively. As one of the reason for this, it has been pointed out that a surface of a quartz column having chemical resistance may be chlorinated by a reactive reagent. Up to today, in the gas-phase chemistry for the superheavy elements, little is known about influence of condition of the column surface for the gas chromatographic behavior. In this study $\Delta_{ads}H$ of $ZrCl_4$ and $HfCl_4$ were measured precisely using a chlorinated and a non-chlorinated quartz column at off-line experiment.

As the radiotracers, ^{88}Zr ($t_{1/2}$ = 83.4 d) and ^{175}Hf ($t_{1/2}$ = 70 d) produced at RIKEN were used. To chlorinate an isothermal column surface, the column was heated at a specific temperature and time flushing He gas saturated with carbon tetrachloride. Then, the tracers were reacted with CCl_4 at 600 ºC for 45 min, and the formed chloride was collected on carbon filter put at upstream of the isothermal part. At the last, the chloride was evaporated at 600 °C, and cumulative yields of the chloride passed through the isothermal column were obtained with γ-ray measurement. Analyzing of chromatograms for various temperatures, we determined relatively $\Delta_{ads}H$ for $ZrCl_4$ and $HfCl_4$ at tracer-scale. Additionally, in order to know the state of silanol groups on the surface of the column, X-ray Photoelectron Spectroscopy (XPS) and Infrared spectroscopy by Attenuated Total Reflection (ATR-IR) were carried out for quartz glass plates of the same material as the isothermal column.

We obtained chromatograms of $ZrCl_4$ and $HfCl_4$ at isothermal temperatures of 100-140 ºC for using the chlorinated column, and 135-160 ºC for non-chlorinated column. It was found that retention times of the chloride for the chlorinated column were faster than those for the non-chlorinated column at the same column temperature. This result suggests that an interaction between the chloride and the column surface is weaken when the column is chlorinated. From the surface analysis results by ATR-IR, there is a possibility that a part of silanol groups was replaced with chlorine. The peak of the silanol groups became much smaller in the chlorinated column. In the conference, we will discuss the difference of $\Delta_{ads}H$ between chlorinated and non-chlorinated column and the results of XPS and ATR-IR in more detail.

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Presenter: Ms SHIRAI, Kaori (Graduate school of science and Technology Niigata University)

Contribution Type: Poster

ID 63

Discussion on Tc and Re mononuclear carbonyls and their cations in gas phase

CAO, Shiwei[1]; WANG, Yang[2]; QIN, Zhi[1]

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Mononuclear Tc and Re carbonyls are the model compounds for the chemical characterization of Bh carbonyls at the single atom chemistry. Our preliminary experiments on the stoichiometry of Re carbonyls in the gas phase deduced that the neutral and the cation species are $Re(CO)_5$ and $[Re(CO)_6]^+$, respectively. We will report here a theoretical study to confirm their stoichiometry by quantum chemistry calculation. At the single atom chemistry in the gas phase, our improved LA-TOF-MS have detected the stable $[Re(CO)_6]^+$, $[W(CO)_5]^-$, $[Ru(CO)_5]^+$ and $[Os(CO)_5]^+$ successfully. The latter three species are isovalent to the neutral $Tc(CO)_5$ and $Re(CO)_5$, which are difficult to be characterized with conventional methods. In the current work, DFT calculations have revealed that, among the $[M(CO)_x]^{\pm}$ (M = Mo, Tc, Ru, W, Re, Os; x = 1~7) species with a specific central metal atom/ion, the species with the lowest energies are deduced to be $[Re(CO)_6]^+$, $[W(CO)_5]^-$, $[Os(CO)_5]^+$ and their lighter homologues. The result fits on well with the LA-TOF-MS experiments. The species with the even higher coordination numbers are not stable, weakly bonded or tagged by the extra CO ligands. However, in the single atom reactions in gas phase, the affinity of molecular hydrogen or oxygen is weaker than CO for $[M(CO)_x]^+$ in the mixture of $CO/H_2/O_2$, which means that in an He/CO atmosphere with trace amount (<0.006%) of H_2 and/or O_2, the predominant species are still believed to be $[M(CO)_x]^+$. The conclusions are also consistent with the results of LA-TOF-MS. Considering the neutral carbonyl complexes, $Tc(CO)_5$ and $Re(CO)_5$ are deduced to have lowest relative energy among their mononuclear carbonyls with different coordination numbers, respectively. Compared with their isovalent species $[W(CO)_5]^-$ and $[M(CO)_5]^+$ (M = Ru, Os) from LA-TOF-MS results, $Tc(CO)_5$ and $Re(CO)_5$ are deduced to be stable and predominant in the single-atom chemistry in the gas phase. Further experiments will concentrate on the impact of the atomic hydrogen and oxygen on the formation of such carbonyl complexes.

Presenter: Dr CAO, Shiwei (Institute of Modern Physics, Chinese Academy of Sciences)

Contribution Type: Poster

ID 66

Research on Superheavy Nuclei at the Velocity Separator SHIP

HOFMANN, Sigurd

GSI Helmholtzzentrum für Schwerionenforschung

The study of heavy and superheavy nuclei and elements was proposed as a major research topic when GSI, the Gesellschaft für Schwerionenforschung, was founded in Darmstadt, Germany, in 1969. A review will be presented on early optimistic expectations and subsequent disappointments, after initial attempts to produce superheavy nuclei have yielded negative results. As a consequence, a program was initiated for optimizing the technical prerequisites using already well known reactions and decay properties of isotopes of lighter elements. Presented is the improvement of the techniques for separation of the produced fusion products, their detection and identification at the newly constructed separator for heavy ion reaction products SHIP.

The advanced experiments resulted in the discovery of the new elements from 107 to 109 in 1981−84 and, after a further upgrade of the set-up, of the elements from 110 to 112 in 1994−96. The measured decay properties of the produced isotopes of the new elements confirmed the theoretically predicted existence of an area of increased stability of deformed superheavy nuclei located in the vicinity of proton and neutron numbers Z = 108 and N = 162, respectively.

Finally, experiments are described, which confirmed data on spherical superheavy nuclei previously measured at JINR in Dubna. These experiments using radioactive ^{248}Cm as target were considered as preparation for longer lasting irradiations for production of the new elements 119 and 120.

Presenter: Prof. MÜNZENBERG, Gottfried (GSI Helmholtzzentrum für Schwerionenforschung)

Contribution Type: Invited talk for the symposium

ID 67

The study of rhenium pentacarbonyl complexes using single-atom chemistry in gas phase

QIN, Zhi [1]; WANG, Yang[2]; CAO, Shiwei[1]; ZHANG, Jicai[1]; YANG, Jie[1]; HABA, Hiromitsu[2]; FAN, Fangli[1]; KOMORI, Yukiko[2]; TAKUYA, Yokokita[2]; MORIMOTO, Kouji[2]; KAJI, Daiya[2]; WITTWER, Yves[3]; EICHLER, Robert[3]; TÜRLER, Andreas[4]

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Towards chemical characterization of the superheavy element bohrium (Bh), a gas-phase chemical study of rhenium carbonyls was carried out using short-lived radioisotopes produced at a heavy-ion accelerator. The Re isotopes produced in the nuclear reactions of $^{nat}Gd(^{23}Na,xn)^{172-177}Re$ were pre-separated with a gas-filled recoil ion separator and their carbonyls were synthesized in a mixture of inert gas and carbon monoxide. Using a low temperature isothermal chromatography apparatus, the adsorption enthalpies of Re carbonyls were derived to be $\Delta H_{ads} = -42 \pm 2$ kJ mol^{-1} on the Teflon surface by fitting the external chromatograms with a Monte Carlo simulation program. The chemical yield of 25% relative to that of the transport yield for Re by a He/KCl gas-jet was achieved. The laser-ablation time-of-flight mass-spectrometric technique was employed to identify the species of Re carbonyls produced in the gas phase. The most stable species was deduced to be $Re(CO)_5$ based on the mass-spectrometric analysis as well as quantum chemistry calculations.

Presenter: Prof. QIN, Zhi (Institute of Modern Physics, Chinese Academy of Sciences)

Contribution Type: Poster

ID 68

Decay properties of ^{255}Rf and ^{251}No

R. Chakma[1], A. Lopez-Martens[1], K. Hauschild[1], A.V. Yeremin[2], M.L. Chelnokov[2], V.I. Chepigin[2], A.V. Isaev[2], A.A. Kuznetsova[2], O.N. Malyshev[2], A.G. Popeko[2], Yu.A. Popov[2], A.I. Svirikhin[2], E.A. Sokol[2], M.S. Tezekbayeva[2], S. Z. Asfari[3], O. Dorvaux[3], B.P.J. Gall[3]

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Heavy and super-heavy nuclei are of general interest to study the tug of war between the electromagnetic and the nuclear forces. Determining the nature and sequence of states in these nuclei is crucial in understanding the different interactions and the dynamics at play, but yet remains challenging both theoretically and experimentally. A viable experimental approach is to search for and study low-lying metastable states, since their decay properties depend on the nature of the states available at the Fermi surface. Around the N= 152 single-particle gap, isomeric states have been studied in detail in ^{257}Rf[1] and ^{256}Rf[2-5]. Thus, it seemed logical to look for isomeric states in 255Rf. The existence of a spin isomer with a lifetime of 50±17 μs at an approximate excitation energy of 135 keV has been recently suggested [6] in light of isomers seen in lighter N = 151 isotones. We have carried out an experiment to populate isomeric states of ^{255}Rf by the fusion-evaporation reaction ^{50}Ti(^{207}Pb,2n)^{255}Rf. The beam ^{50}Ti of 300 pnA was delivered by the U400 accelerator at FLNR, Dubna. The SHELS [7] separator was used to separate the evaporation residues from the beam and background of other reaction products. The residues were then implanted in the focal plane detector of the GABRIELA [8] setup.

Preliminary results on the decay properties of ^{255}Rf and ^{251}No will be presented. In particular, based on γ and internal-conversion-electron spectroscopy, the decay of a K isomer in ^{255}Rf will be discussed.

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Presenter: Mr CHAKMA, Rikel (Université Paris Sud)

Contribution Type: Contributed talk

ID 70

Heaviest nuclei in covariant density functional theory

AFANASJEV, Anatoli

Mississippi State University

What are the limits of the existence of nuclei? What are the highest proton numbers Z at which the nuclear landscape and periodic table of chemical elements cease to exist? How many neutrons a nucleus with given Z can hold? What are the properties of these exotic nuclei? These deceivable simple questions are extremely difficult to answer. In my presentation, I will try to outline possible answers on these questions obtained in our recent studies within covariant density functional theory (CDFT).

I will start my presentation from an overview of the studies of the heaviest nuclei (actinides and superheavy elements) for which experimental data is available. Using different observables related to the ground state, pairing, rotational, α-decay and single-particle properties, the performance of the state-of-the-art covariant energy density functionals in the mass region of interest is established. Based on these benchmarks, the detailed analysis of the properties of superheavy (Z=100−126) and hyperheavy (Z>126) nuclei will be presented. A special attention will be paid to the role of dynamical correlations in superheavy nuclei and their impact on the ground state and fission properties. I will also discuss the extension of nuclear landscape towards hyperheavy nuclei. The competition of ellipsoidal and toroidal shapes plays an extremely important role in this part of nuclear chart; the latter types of shapes are dominant in Z>134 nuclei. For the first time, we demonstrated possible existence of three islands of stability of spherical hyperheavy nuclei centered around (Z∼138,N∼230), (Z∼156,N∼310) and (Z∼174,N∼410) which are expected to be reasonably stable with respect of spontaneous fission, cluster and α decays. In addition, the results of on-going investigations of superheavy nuclei within the CDFT framework will be presented.

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Presenter: Prof. AFANASJEV, Anatoli (Mississippi State University)

Contribution Type: Invited talk

ID 71

Recent developments in quasifission

D.J. Hinde, M. Dasgupta, K. Banerjee, D.Y. Jeung, C. Simenel, E.C. Simpson, B.M.A. Swinton-Bland, E. Williams, I.P. Carter, K.J. Cook, D.C. Rafferty, S. Kalkal, C. Sengupta, K. Vo-Phuoc
Australian National University, Canberra

H.M. David[2], Ch.E. Düllmann[2,3,4], J. Khuyagbaatar[2,3], A. Yakushev[2,3], K. Eberhardt[3,4], B. Kindler[2], B. Lommel[2], Ch. Mokry[3,4], J. Runke[2,4], P. Thörle-Pospiech[3,4]

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Quasifission competes strongly with fusion in reactions forming superheavy elements. The heaviest element that currently can be created using a ^{48}Ca beam is Z=118 (Oganesson). To form still heavier elements by fusion, use of heavier projectiles is necessary.

In general it is understood that heavier projectiles such as ^{50}Ti, ^{54}Cr, ^{64}Ni give lower yields of heavy elements than does ^{48}Ca. In cold fusion, this seems to be associated with the proton and neutron magic numbers as well as the neutron-richness of ^{48}Ca. Evidence is seen in both evaporation residue cross sections and fission characteristics, as will be presented.

In the case of actinide (hot fusion) reactions, it is not clear whether it is the neutron-richness and low Z of ^{48}Ca that has led to the successful synthesis of superheavy elements from 112 to 118, or whether its doubly-magic characteristic is also critical. It is important to understand this question to understand the physics inputs required in models of quasifission and fusion in superheavy element synthesis reactions, and to predict cross sections for reactions to create new superheavy elements in future.

To address this issue, measurements of quasifission mass-angle distributions have been carried out at the Australian National University. Projectiles of ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe and ^{64}Ni bombarded targets of ^{249}Cf, ^{248}Cm, ^{244}Pu, ^{238}U, ^{232}Th and ^{208}Pb. Beam energies from below-barrier to above-barrier have been measured. With an enhanced MWPC detector setup allowing centre-of-mass angular coverage from 20 to 160 degrees, these combined mass and angle data reveal the difference in the typical reaction outcomes, and the associated mass evolution dynamics in these reactions. This new information is complementary to previous fission mass-energy distribution measurements, and throws light on the difference between cold fusion and hot fusion reaction dynamics.

Presenter: Prof. HINDE, David J. (Australian National University)

Contribution Type: Invited talk

ID 72

Electronic Structure Theory for the whole Periodic Table of the Elements

KNECHT, Stefan

Department of Chemistry and Applied Biosciences, ETH Zürich

Computational modeling has undoubtedly become an integral part of chemical research. For instance, providing an understanding of the nature of a chemical bond and how it relates to the chemical reactivity of a molecule is of central interest in chemistry. To rationalize such properties at a molecular level requires a tailor-made quantum chemical framework that provides the means to accurately describe the central piece of information relevant to chemistry, viz., the electronic structure. Its determination relies on the solution of the quantum mechanical equations for the electronic many-body problem. Whereas solving the electronic Schrödinger equation (often) yields sufficiently accurate results for light elements, i.e., those of the upper part of the periodic table, this is generally not the case for heavy elements, in particular not for actinide and transactinides. For the latter, an explicit consideration of the theory of special relativity is required.

In this talk, the development and application of multiconfigurational wave-function based quantum chemical methods [1-5] is presented that are designed to accommodate the needs to account for the correlated motion of the electrons as well as for relativistic effects in a rigorous manner.

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Contribution Type: Contributed talk

ID 73

Heavy Element Research at Texas A&M University

FOLDEN, Charles

Texas A&M University

In recent years, the heavy elements program at Texas A&M University has focused on several areas: the study of nuclear reactions to produce spherical, shell-stabilized nuclei; offline chemical experiments to develop techniques that could be applied in future superheavy element experiments; and improvements to our instruments to enhance online capabilities. The chemical experiments will be discussed in a separate contribution to this conference, so this talk will focus on the other two topics.

In a series of experiments conducted with the Momentum Achromat Recoil Spectrometer (MARS), our group has studied the influence of projectiles with $Z > 20$ on the cross section for reactions with lanthanide targets. The compound nuclei in these reactions are near doubly magic ^{208}Pb and have excitation energies and deformations that are comparable to those observed in compound nuclei produced in superheavy element experiments. We have systematically measured cross sections for ^{40}Ar, ^{44,48}Ca, ^{45}Sc, ^{50}Ti, and ^{54}Cr reacting with a variety of lanthanide targets. The data show a strong dependence of cross section on projectile, and these results has been compared against the results of a theoretical model. The latter suggests that cross sections are heavily dependent on the average difference between the fission barrier and the neutron binding energy of the compound nucleus, as well as the influence of collective effects to level density. These results suggest that the discovery of new elements using projectiles other than ^{48}Ca could be very difficult.

The gas-filled separator previously known as SASSYER has been installed on a beamline and is in the final stages of preparation. Offline commissioning is imminent and first online commissioning experiments will be conducted in the near future. The gas-filled separation technique should substantially increase the efficiency of our experiments, and a new focal plane detector will be used that will increase the number of pixels by a factor of approximately 20 compared to MARS.
This talk will summarize this work, the most recent results, and future plans.

Contribution Type: Poster

ID 74

The species identification of Mo, W, and Re carbonyl complexes with laser-ablation time-of-flight mass-spectrometry

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The study of transactinide elements in the form of metal-carbonyl complexes is a highly desirable project as it is expected to provide new insight into the chemical properties of these elements and the influence of relativistic effects. First investigations of $Sg(CO)_6$, as well as $Tc(CO)_5$ and $Re(CO)_5$, being a model system for $Bh(CO)_5$, were strongly harmed by low chemical yields. [1~3] This makes it necessary to further study the formation of metal-carbonyl complexes under single-atom-chemistry conditions. In this work, a modified laser-ablation time-of-flight mass-spectrometer was used to obtain mass spectra of group 6 and group 7 transition metal carbonyls by subjecting Mo, W and Re metal targets to CO/He gas mixtures . In this system, an extension pipe is installed downstream of the metal targets as an additional reaction zone in order to increase the reaction time and strengthen the interaction between the metal ions and CO gas, so only the most stable products formed in gas phase are observed, resembling gas chromatography experiments. [3] The influence of impurities on the formation of these carbonyls was investigated by adding H_2/O_2 to CO/He gas mixtures since a significant influence on group 6 and group 7 elements was expected. [2] $[Mo(CO)_6]^+$, $[W(CO)_6]^+$, and $[Re(CO)_6]^+$ were identified to be the most stable products in He/CO gas mixtures. No intermediates or other significant products was observed due to the extension pipe. Small amounts of $[MoH(CO)_6]^+$, $[WH(CO)_6]^+$, and $[Re(CO)_5(H_2)]_+$ were observed when adding 14% of H_2 to He/CO gas mixtures. However, hydride ions can be ignored when the H_2 concentration is lower than 0.9%, which suggests that trace amounts of H2 gas will not strongly influence the formation of these carbonyl ions. Additionally, significant amounts of $[ReO_2(CO)_4]^+$, $[MoO(CO)_5]^+$, and $[WO(CO)_5]^+$ could be observed when O_2 was more than 0.09%, 0.02%, and 0.006%, respectively. By varying the concentration of H_2/O_2, formation of various oxides is observed, from which an estimate of their affinity towards oxide formation increasing in the order Re < Mo < W can be given. Preliminary studies using the FORA-setup[4] imply that Tc is not very sensitive towards O_2 traces, hinting that Bh may not be strongly affected by O_2 as well, which would be an advantage over Sg, which is potentially more sensitive towards O_2 than W. [5] Thus, group 6 elements appear to be more prone to form side-products upon addition of H_2/O_2 than group 7 elements.

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Presenter: Dr WANG, Yang (RIKEN Nishina Center for Accelerator-Based Science)

Contribution Type: Contributed talk

ID 75

Monte-Carlo simulation of ion distributions in a gas cell for multinucleon transfer reaction products at LENSHIAF spectrometer

HUANG, Wenxue[1]; WANG, Yong-sheng[2]; TIAN, Yu-lin[1]; WANG, Jun-ying[1]; LI, Cheng[3]; ZHANG, Feng-shou[4]; ZHAO, Kai[5]; ZHOU, Xiao-hong[1]; XU, Hu-shan[1]

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The study on the nuclear structure and exotic decay property of neutron-rich isotopes is an important subject in nuclear physics research nowadays. To date, by using nuclear fusion-evaporation reaction, projectile fragmentation and proton/neutron-induced fission, and spontaneous fission, we can only produce neutron-rich isotopes with small charge number Z. For significantly more neutron-rich isotopes with higher Z>70, there is no appropriate method to produce except multinucleon transfer (MNT) reaction. The MNT reaction is one promising way to produce neutron-rich heavy nuclei and even super heavy nuclei and attracts more and more attentions theoretically and experimentally.

In the ongoing big project HIAF (High Intensity heavy-ion Accelerator Facility), a Low Energy Nuclear Structure spectrometer called LENSHIAF specific to MNT reactions will be designed and constructed. In this spectrometer, the researches will be concentrated on synthesis and identification of new neutron-rich nuclides, and on the study of their nuclear structure and decay properties. In the very preliminary design, MNT products will be stopped in a gas cell filled with helium. Following up are a sextupole ion guide, a radio-frequency quadrupole cooler and buncher, and successive workstations for collinear laser spectroscopy, decay spectroscopy and mass measurements by Penning traps and multi-reflection time-of-flight mass spectrometer. Among all the processes and devices, the most challenge part is how to collect and stop efficiently the high-energy products from the MNT reactions into the gas cell. It is the first part of difficulties we have to solve.

In the conference, the motivation, conceptual design and working principle of this spectrometer will be introduced. Monte-Carlo simulation results will be presented in detail.

Presenter: Prof. HUANG, Wenxue (Institute of Modern Physics, Chinese Academy of Sciences)

Contribution Type: Poster

ID 76

The Status of SHANS

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Institute of Modern Physics, Chinese Academy of Sciences

Since the commission of the gas-filled recoil separator SHANS in 2008, eight new proton-rich isotopes in the mass region with 89<=Z<=93 were synthesized based on the ^{36,40}Ar and ^{40}Ca induced fusion evaporation reactions. Figure 1 shows the mass region of interest, in which the new isotopes produced on this setup are indicated.

In my talk, the present status of SHANS will be introduced in detail, including the detection system and digital electronics. The newly measured decay properties for U and Np isotopes will be summarized. The newly established alpha-decay systematics for these isotopes and the manifestation of N=126 shell closure in the most proton-rich nuclear region will be shown. Lastly, the future plan for our setup will be presented.

Contribution Type: Contributed talk

ID 77

Online studies with thallium and the prospects for a future chemistry experiment with nihonium

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[1]Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research; [2]Advanced Science Research Center, Japan Atomic Energy Agency; [3]Paul Scherrer Institute; [4]Université de Strasbourg, CNRS

So far, only two experiments targeting the chemistry of the superheavy element (SHE) nihonium (Nh, Z=113) have been reported on, both applying fast gas-phase adsorption chromatography. A rather volatile chemical species of nihonium was observed in the very first experiment, using a direct chemical approach without physical pre-separation. The transported Nh-species was found to have a weak interaction with inert surfaces and an enhanced reactivity towards a gold surface [1]. As the chemical speciation of nihonium remained unclear, the same experiment was repeated under generally more inert conditions (i.e., highly purified inert carrier gas as well as exclusively Teflon surfaces between the production site and the chromatography detector array) behind the Dubna Gas-Filled Recoil Separator (DGFRS) [2]. The non-observation of any Nh-related events in the second study was attributed to the preservation of Nh in its elemental state and a higher-than-expected adsorption interaction with a Teflon surface [2,3]. Consequently, it was concluded that a different chemical species of Nh was formed and transported during the very first attempts.

To study the chemical speciation of Nh and to assess the prospects of future experiments with the SHE, a series of model studies with its lighter homolog thallium (Tl, Z=81) was carried out at the U400 accelerator facility of the Flerov Laboratory of Nuclear Reactions, Dubna, Russia. Short-lived ^{184}Tl ($t_{1/2}$=10.1 s) was synthesized in the nuclear fusion-evaporation reaction ^{141}Pr(^{46}Ti, 3n)^{184}Tl and separated from the primary heavy ion beam as well as nuclear reaction by-products by means of the Separator for Heavy ELement Spectroscopy (SHELS) [4]. The newly developed chemistry setup in the focal plane of the separator consists of a recoil transfer chamber and a directly attached isothermal chromatography section. Different gas-phase compositions with a varying redox potential were tested in order to optimize the formation and transport of the observed volatile chemical species of Tl. Both, gamma- and alpha-spectroscopy were employed for the assessment of adsorption characteristics. The results of these investigations as well as their consequences for a next chemistry experiment with nihonium will be presented.

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Presenter: Dr STEINEGGER, Patrick (Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research)

Contribution Type: Invited talk

ID 78

Anion-exchange Behavior of Zr, Hf, and Th in Nitric Acid - Toward the Chemical Study on Element 104, Rf

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The chemical properties of superheavy elements (SHEs) with $Z \geq 104$ are expected to deviate from the periodicity of their lighter homologues in the periodic table due to the strong relativistic effects. Since the nuclides of SHEs can be produced only by nuclear reactions with very low production rates (≤ few atoms /min) and have short half-lives ($T_{1/2}$) (≤ 1 min), an automated and rapid chemical separation apparatus is needed for the chemical experiments of SHEs. In our previous work[1], we developed the automated batch-type solid-liquid extraction apparatus (AMBER) and investigated the anion-exchange behavior of $_{104}$Rf to obtain the distribution coefficients (K_d) of Rf in hydrochloric acid. Herein, we focus on the formation of the Rf nitrate complexes because the clear difference in nitric complexation of Th (pseudo homologue) from that of Zr and Hf (homologues) was observed: Th forms an anion complex while Zr and Hf do not. Toward the anion-exchange experiment in nitric acid using AMBER, in this study, anion-exchange experiments of Zr, Hf, and Th in nitric acid were performed by batch method to search the rapid reaction system and to obtain the comparison data for the chemical study of Rf. The ^{88}Zr ($T_{1/2}$ = 83.4 d) and ^{175}Hf (70.0 d) nuclides were produced in the ^{89}Y(p,2 n)^{88}Zr and ^{nat}Lu(p,x n)^{175}Hf reactions (nat = natural isotopic abundance), respectively, using AVF cyclotron at Research Center for Nuclear Physics, Osaka University. The ^{234}Th (24 d) was separated from ^{238}U by solvent extraction. The 20-80 mg of anion-exchange resin (Aliquat 336 resin and Adogen 464 resin) and the Zr, Hf, and Th dissolved in 2.3 - 9.7 M HNO_3 (0.5 mL) were mixed in a PP tube and the mixture was shaken for 0.5 - 300 min using a vortex mixer at 25℃. Based on the gamma-ray activities of ^{88}Zr, ^{175}Hf, and ^{234}Th measured by a Ge semiconductor detector, the K_d values were evaluated. For both the Aliquat 336 and Adogen 464 resins, the anion-exchange reaction equilibrium was achieved for Th by shaking for 1 min, while most of Zr and Hf were not absorbed on the resins. This result indicates that the times to reach chemical equilibrium for the anionic species of the present reaction system is considered to be sufficiently fast to investigate the Rf nitrate complexes; the present reaction system would be applicable for ^{261}Rf ($T_{1/2}$ = 68 s) experiment. We also conducted quantum chemical calculations on nitrate complexes of these elements to understand electronic states of the extracted chemical species.

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Presenter: Mr WATANABE, Eisuke (Graduate School of Science, Osaka University)

Contribution Type: Poster

ID 80

Fast microfluidic extraction of Sg homologues at new joint CTU, UiO and NPI facility in Rez (CZE)

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Recently, a new experimental facility was set up at the U-120M cyclotron at the Nuclear Physics Institute of the Czech Academy of Sciences in Rez (CZE) within its CANAM infrastructure. It is equipped with target chamber and gas-jet (GJ) transfer system from the University of Oslo (NOR), and microfluidic liquid-liquid extraction (LLX) system from the Czech Technical University in Prague (CZE) that has been installed in a new chemical laboratory. Now, options for fast aerosol into liquid flow conversion are under development. Combining all these systems should constitute a platform for fast transport and fast low-reagent-consumption liquid chemistry studies of on-site produced short-lived radionuclides.

In this work, recent results of microfluidic liquid-liquid extraction of Mo and W (as homologues of Sg) from diluted nitric acid into Cyanex®600 in 1% n-octanol and kerosene will be discussed. First, microfluidic slug-flow capillary technique and vortex batch technique will be compared showing enhanced mass transfer properties in favor of microfluidics. In parallel, choice of Cyanex®600 as a group 6 fast extracting agent will be justified by comparison with widely used HDEHP extractant. Consequently, dependencies of Mo/W equilibrium distribution ratio on pH, nitrate concentration and Cyanex®600 concentration will be shown. Based on the slope analyses of such dependencies, mechanism of Mo/W extraction in the Cyanex®600/nitric acid system will be proposed. In the end, retention time, as one of the ultimate parameters for short-lived-radionuclide extraction, will be discussed with respect to the system in question and its possible optimization.

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Presenter: Mr BARTL, Pavel (Czech Technical University in Prague)

Contribution Type: Poster

ID 83

Optimizations of the TASCA-COMPACT setup towards chemical studies of nihonium (element 113)

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The chemical and physical properties of transactinide elements are influenced by strong relativistic effects [1]. In the last decade, chemical studies on the SHE focused on the investigations of flerovium (Fl, Z=114) [2, 3]. The focus in the community is now shifting to the determination of chemical properties of nihonium, Nh. Due to its unpaired electron in the $7p_{1/2}$ orbital, relativistic calculations suggest Nh to be more reactive and less volatile than Fl or Cn (Z=112). It is nevertheless expected to have a lower reactivity than its lighter homolog Tl [4,5]. Experimental studies on Nh are challenging, due to its low production rates and relatively short half-lives. For chemistry experiments ^{284}Nh with a $T_{1/2}$ of ~1 s appears to be one of the most ideal isotopes. It is best produced indirectly via the reaction ^{243}Am(^{48}Ca, 3n)^{288}Mc. Its production rate is similar to that of Fl in the ^{48}Ca+^{244}Pu reaction. In order to reduce the amount of unwanted background, we perform chemical experiments behind a physical pre-separator like TASCA. Our TASCA-COMPACT setup allows the safe detection of single atoms through their characteristic nuclear decay chains and is suitable for studying the interaction strength of these atoms with Au or SiO_2 surfaces in a wide range of bond strengths [6].

The first chemistry experiment on Nh was performed at FLNR Dubna [7]. Based on the observation of five decay chains attributed to Nh isotopes, a high reactivity towards Au was concluded. The experiment suffered from substantial background, as no physical pre-separator was used. In a second experiment, performed behind the DGFRS separator, no decay chains originating from Nh isotopes were observed [8]. In an experiment performed at TASCA, no decay chains attributed to Nh isotopes were observed. This was attributed to be due to either the higher chemical reactivity of Nh compared to Fl, or limited statistics. This situation calls for improved experiments. On the way to such studies, technical optimizations to the experimental setup were performed, mainly to increase the overall efficiency for both inert as well as for more reactive species. For this, upgrades on the design of the RTC and on the connection lengths were implemented. Several experimental studies with short-lived Hg, Pb, and Tl isotopes were carried out. The technical optimizations and the results will be discussed, demonstrating the readiness of the TASCA-COMPACT setup for chemical studies of Nh.

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Presenter: Dr LENS, Lotte (GSI, Darmstadt)

Contribution Type: Poster

ID 84

Development and first results from a novel "α-ToF" detector used with a multi-reflection time-of-flight mass spectrograph.

NIWASE, Toshitaka[1]; WADA, Michiharu[2]; SCHURY, Peter[2]; ITO, Yuta[3]; KIMURA, Sota[2]; KAJI, Daiya[4]; ROSENBUSCH, Marco[4]; . WATANABE, Yutaka[2]; HIRAYAMA, Yoshikazu[2]; MIYATAKE, Hiroari[2]; MOON, J. Y.[5]; ISHIYAMA, Hironobu[4]; MORIMOTO, Koji[4]; HABA, Hiromitsu[4]; TANAKA, Taiki[6]; ISHIZAWA, Satoshi[4]; TAKAMINE, Aiko[4]; MORITA, Kosuke[1]; HERMANN, Wollnik[7]

[1]RIKEN/Kyushu Univ.; [2]KEK; [3]JAEA; [4]RIKEN; [5]IBS/KEK; [6]The Australian National University; [7]New Mexico State University, Las Cruces

We have developed a novel detector, referred to as an "α-ToF detector", for correlated measurements of atomic masses and decay properties of very rare, short-lived nuclides. One major purpose of this detector is to reduce the background event rate during mass measurements of superheavy nuclides using a multi-reflection time-of-flight mass spectrograph (MRTOF-MS). Using the MRTOF-MS, we have measured more than 80 masses of fusion-evaporation products including several transfermium elements [1], which were provided from RIKEN's gas-filled recoil ion separator, GARIS-II. However, if we go further into the superheavy element region, we must distinguish very rare events (single event per day) from background events which might originate from scattered ions, molecular ions, or dark signals in the ToF detector. The α-ToF detector can correlate a ToF signal and successive decay signals from alpha-decay or spontaneous fission. Coincidence measurements with a typical gate period of 2--3 half-lives can eliminate background events, if the rate is reasonably lower than the inverse lifetime. An offline test of the α-ToF detector has shown that the ToF signal efficiency for 5.48 MeV α-rays is more than 90% with a time resolution of 251.5(68) ps, with an energy resolution of 141.1(9) keV. We have also performed an online test with a short-lived radium isotope, ^{207}Ra, and found that in addition to dramatically reducing the background rate, the detector could also be used to determine the decay lifetime using the time interval between the ion's arrival and the decay signal. We discuss the performance of the alpha-ToF detector and applications for various nuclear spectroscopy.

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Presenter: Mr NIWASE, Toshitaka (RIKEN/Kyushu Univ.)

Contribution Type: Poster

ID 85

ODIn – Off-line Deposit Irradiation as a baking-in procedure for heavy-element targets

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Superheavy elements are produced via heavy-ion fusion reactions, using intense beams. Target production [1], especially of actinide elements as they are used to produce the heaviest elements, relies on methods like Molecular Platting (MP) [2]. Long-term stability of the targets is achieved after a so-called "baking-in" procedure, in which the fresh target is exposed to successively increasing beam intensities. These lead to non-trivial physical and chemical transformations, which have hitherto mostly been described by studies using microscopic methods [3], Atomic Force Microscopy and Scanning Electron Microscopy. More detailed spectroscopic investigations of the irradiation effects are still pending, so that the exact nature of the processes during baking has not yet been fully elucidated [4,5,6].

We report on the design, construction, and first commissioning of the ODIn setup suitable for Off-line Deposit Irradiation. This is installed at Helmholtz Institute Mainz and comprises an ion gun and an electron gun. The main aims of the ODIn project are (i) accelerator independent irradiation of freshly prepared targets to obtain long-term stability independent of accelerator operation, and (ii) the possibility to study the chemical and physical processes during the irradiation. In a first phase, the changes induced by Coulomb barrier heavy ion beams and by the low-kinetic energy beams from ODIn will be compared to establish the proper working regime with ODIn.

For first experiments, ^{nat}Pb and ^{147}Sm targets are used. Pb is a typical target element in cold fusion reactions. Furthermore, lead-oxide compounds show a characteristic variety of colours based on the oxidation state, which is well documented in the literature. By analytical identification of the resulting lead compounds, it appears possible to deduce the conditions after influence of the beam.

Sm is a homolog of the heavier actinides used in cold-fusion reactions. In addition, ^{147}Sm is a primordial alpha-emitter, facilitating the use of alpha spectroscopy [8,9] before and after irradiation to benchmark the quality of targets. The status of the ODIn project will be discussed at the conference.

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Presenter: Mr MEYER, Carl-Christian (JGU Mainz / HIM)

Contribution Type: Poster

ID 86

Fusion Dynamics for Hot Fusion Reactions revealed in Quasielastic Barrier Distributions

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The study of Coulomb barrier distributions is of fundamental importance in understanding heavy-ion induced fusion reactions towards syntheses of superheavy nuclei[1-3]. Cross sections of the reactions for producing new elements are predicted to be much smaller than those for the existing elements[4-6]. They are also known to be particularly sensitive to the incident energy. One of the most direct information for determining the optimum incident energy is provided by the barrier distribution. This work aims at precisely obtaining the barrier distribution of heavy-ion induced reactions by measuring the quasielastic (QE) scattering, in order to clarify the relation between the barrier distribution and the optimum incident energy at which the evaporation residue cross section is maximized. To this end, the excitation functions of QE scattering cross sections S_{QE} relative to the Rutherford cross sections S_R for ^{22}Ne+^{248}Cm, ^{26}Mg+^{248}Cm, and ^{48}Ca+^{238}U systems were measured. What is new in this method is measuring the recoiled nuclei at forward angles ($\theta \sim 0°$) using GARIS. This method enables us to derive the barrier distribution for angular momentum $l \sim 0$ concerned with superheavy nuclei synthesis. The quasielastic scattering events were well separated from deep-inelastic events by using GARIS and its focal plane detectors. The QE barrier distributions were extracted for these systems, and compared with coupled-channels calculations[7]. The results of the calculations indicate that the barrier distributions were strongly affected by the deformation of the target nuclei. In addition, the barrier distributions were influenced by vibrational and rotational excitations of the projectile nuclei. The evaporation residue cross-sections of the hot fusion reactions ^{22}Ne+^{248}Cm, ^{26}Mg+2^{48}Cm, ^{48}Ca+^{238}U and ^{48}Ca+^{248}Cm – relevant to the synthesis of Sg (atomic number Z = 106), Hs (Z = 108), Cn (Z = 112) and Lv (Z = 116), which are the frontier of the known superheavy nuclei – were found to peak at an energy between the experimental average Coulomb barrier height and the barrier height for the side collision. Evidently the hot fusion reactions take advantage of a compact collision geometry with the projectile impacting on the side of the deformed target nucleus.

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Presenter: Dr TANAKA, Taiki (The Australian National University)

Contribution Type: Contributed talk

ID 87

Ab-initio Monte Carlo melting simulations of oganesson

SMITS, Odile[1]; JERABEK, Paul[2]; PAHL, Elke[3]

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The elements in the last column of the periodic table owe their name to their common property: because of their full valence electron shell these elements are inert and have therefore a very low melting temperature and the noble gases are thus in a gaseous phase at ambient conditions. The heaviest noble gas, oganesson, might be an exception: due to its incredible large nuclear mass, relativistic contributions increase the binding energy, hinting oganesson to be a solid at room temperature.

Here we present our study on the melting temperatures of the heavy noble gases by means of Parallel Tempering Monte Carlo (PTMC), through either direct sampling of the bulk and from a finite cluster approach. This method allows us to obtain the interaction energy of an N atomic system for a range of temperatures numerically by repeated random sampling. The melting temperatures are determined from the equilibrium heat capacity as the maximum of the heat capacity curves. The PTMC simulations are conducted for ab-initio two- and three-body potentials which have been obtained by state-of-the-art relativistic coupled-cluster theory.

Presenter: Dr SMITS, Odile (Massey University)

Contribution Type: Poster

ID 88

Superheavy Studies at GANIL-SPIRAL2

PIOT, Julien[1]; SAVAJOLS, Herve[2]; STODEL, Christelle[2]; ACKERMANN, Dieter[3]; SULIGNANO, Barbara[4]; DROUART, Antoine[5]; VANDEBROUCK, Marine[2]; FERRER, Rafael[6]; MANEA, Vladimir[7]; MOORE, Iain[8]; WENDT, Klaus[9]; HAUSCHILD, Karl[10]; LOPEZ-MARTENS, Araceli[10]; DORVAUX, Olivier[11]; GALL, Benoît[11]; LEBLANC, François[12]; CACERES, Lucia[2]; DELAHAYE, Pierre[2]; FLECHARD, Xavier[13]; FRANCHOO, Serge[12]; DE GROOTE, Ruben[8]; LECESNE, Nathalie[2]; RETAILLEAU, Blaise-Maël[2]; ROMANS, Jekabs[6]; VAN DUPPEN, Piet[6]

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The exploration of the region of nuclei with Z >100 is steadily progressing towards heavier masses due to the advances in experimental techniques. Many experiments have been devoted to the spectroscopic properties of transfermium nuclei, revealing the fundamental importance of shell effects in this region.

The Super-Separator-Spectrometer S_3 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.

S_3 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.

S_3 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.

The S_3-Low Energy Branch 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 S_3. 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 S_3 and its detection systems and give an overview of the Physics Cases planned for the first experiments.

S_3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and by the E.C.FP7-INFRASTRUCTURES 2007, SPIRAL2 Preparatory Phase, Grant agreement No.: 212692.

SIRIUS has been funded by the CPIER (Contrat Plan Etat Inter Régional)

Presenter: Dr PIOT, Julien (CNRS/GANIL)

Contribution Type: Contributed talk

ID 89

Schiff Base Coordination Chemistry with Tetravalent Cations

KLAMM, Bonnie; WINDORFF, Cory; CELIS-BARROS, Cristian; MARSH, Matthew; MEEKER, David; ALBRECHT-SCHMITT, Thomas

Florida State University

Previous groundbreaking experiments on tetravalent Rf have shown that its physicochemical properties are in agreement with its position in Group 4 in the periodic table. However, recent literature studies revealed several unexpected chemical behaviors of Rf in HF solutions, where fluoride complex formation is significantly different than that of its Zr and Hf homologues. In this present study, a Schiff base ligand capable of stabilizing the tetravalent state has been used to complex a series of actinide (Th, U, Np, Pu), lanthanide (Ce), and transition metal (Zr, Hf) elements. This study may provide insight into the chemistry of Rf(IV). Our interest in the chemistry of the early tetravalent actinides is based on periodic trends throughout the series. These elements and their trends provide a means to understand the structural, electronic, and chemical properties of the early actinide elements. These complexes allow for comparison across a series of elements using various structural, spectroscopic, and theoretical techniques to explore their bonding differences and redox behavior. Knowledge of the chemistry of these lighter tetravalent metal complexes may be used to elucidate the behavior of tetravalent Rf and to understand its fundamental chemistry.

Presenter: Ms KLAMM, Bonnie (Florida State University)

Contribution Type: Contributed talk

ID 90

SHE-Mass-II setup for direct mass measurement of hot-fusion superheavy nuclides

WADA, Michiharu[1,2,3]; SCHURY, Peter[3]; MIYATAKE, Hiroari[3]; WATANABE, Yutaka X.[3]; HIRAYAMA, Yoshikazu[3]; WOLLNIK, Herrmann[3]; KIMURA, Sota[4]; ISHIZAWA, Satoshi[4]; NIWASE, Takaaki[4]; ROSENBUSCH, Marco[4]; KAJI, Daiya[4]; MORIMOTO, Koji[4]; HABA, Hiromitsu[4]; TAKAMINE, Ico[4]; TANAKA, Taiki[4]; ISHIYAMA, Hironobu[4]; ITO, Yuta[5]; MOON, Jun Young[6]; MORITA, Kosuke[7]

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The SHE-Mass facility was a system with a multi-reflection time-of-flight mass spectrograph (MRTOF-MS) [1] and a cryogenic gas catcher coupled to the GARIS-II separator at RILAC. With this setup we have measured the masses of more than 80 fusion-evaporated products including several trans-fermium nuclides [2,3,4,5] After shutdown of GARIS-II, we rebuild a similar setup, i.e., the SHE-Mass-II, at the new location of GARIS-II in the E6 experimental room of RIKEN RI-Beam Factory.

The new setup has a single-stage triplet ion trap system, which means that ions are directly injected to the MRTOF-MS from the gas catcher to achieve high efficiency. The whole setup including vacuum pumps, a gas cylinder, and electric circuits is mounted on a single base plate, which is movable on rails so as to make coupling and decoupling to the GARIS-II quickly. Furthermore, the gas catcher chamber and the ion trap chamber are mounted on a two-dimensional rail system that allows us easy maintenance of the internal structures of the setup.

A drawback of the new setup is that more contaminant ions could be expected due to the difficulty of intermediate mass selection. In the previous setup, we had a 5 m-long beam line between the two ion traps where we could place a Bradbury-Nielsen (BN) ion gate [6] to select a single mass number. However, the new setup has only a 50 cm distance between the trap and the MRTOF-MS where a BN gate can be installed. We developed a 10 times finer gate device made of 13 μ-thick wires with 130 μ intervals which can deflect a 1 keV/q ion beam by 65 mrad with a ±100 V pulse. Such fine structure makes sharp cut of the ion beam.

We have also replaced the time-of-flight detector with a newly developed α-TOF detector, which records the time-of-flight signal and the successive α-decay signals, simultaneously. A first online commissioning of the SHE-Mass-II setup has been performed in December 2018 and we found that the α-TOF detector significantly reduced the background level [6]. An offline experiment for tuning of the setup using ^{252}Cf fission source is also in progress [7].

We are ready to start direct mass measurement of hot-fusion super heavy elements, ^{288}Mc and ^{284}Nh, with the SHE-Mass-II setup.

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Presenter: Prof. WADA, Michiharu (WNSC, IPNS, KEK)

Contribution Type: Invited talk

ID 91

The discovery of element 113

MORIMOTO, Kouji

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In the experimental program aiming to discover the 113th element produced by the $^{209}Bi(^{70}Zn, n)^{278}113$ reaction, we succeeded to observe three decay chains in 2004, 2005 and 2012 [1-3]. Finally the IUPAC would give the research group a rights of naming. The element 113 was named "Nihonium" and"Nh". In this talk all the results related to the discovery of 113th element will be presented. For the next, a new program aiming to produce further new elements 119th and 120th via hot fusion reaction was started in collaboration with RIKEN, Oak Ridge National Laboratory (ORNL), Kyushu-Univ., Yamagata-Univ., Osaka-Univ., Niigata-Univ., Tohoku-Univ., Saitama-Univ., Tennessee-Univ. and Japan Atomic Energy Agency (JAEA). The new collaboration group named "nSHE collaboration". The status and future plans of new element search by nSHE collaboration at RIKEN also will be presented in the conference.

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Contribution Type: Invited talk for the symposium

ID 93

High accuracy calculations of atomic properties of rare gases including oganesson, element 118.

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University of Groningen

The first and second ionization potentials of rare gases, including the superheavy element oganesson (Z=118), were calculated within the relativistic coupled cluster (CCSD(T)) approach. Influence of various computational parameters (number of correlated electrons, choice of the Hamiltonian, basis set, etc.) on the obtained results was investigated. Our final values are obtained using the 4-component Dirac Hamiltonian, all electrons are correlated, and the results are extrapolated to the complete basis set limit and corrected for the Breit and QED contributions. We also perform a calculation of the electron affinity of oganesson, which is expected to be the only rare gas with a positive electron affinity.

Presenter: Ms GUO, Yangyang (RUG)

Contribution Type: Poster

ID 94

Atomic and Chemical Properties of Lawrencium (Lr, Z = 103) and an Outlook to the Transactinides

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The first ionization potential (IP_1) of an atom, one of the fundamental atomic properties, yields information on the valence electronic structure. Recently, we successfully determined the IP_1 value of heavy actinide elements including lawrencium (Lr, Z=103) on scales of one atom at a time by using a surface ion-source installed in the Isotope Separator On-Line (ISOL) at the JAEA tandem accelerator [1,2]. The experimental IP_1 value of Lr agrees with theoretical calculations that suggest its electronic configuration to be [Rn]$7s^2 5f^{14} 7p_{1/2}$ as a result of the strong relativistic effects.

This result motivates us to explore the volatility of elemental Lr because the volatility or adsorption strength on a metallic surface is expected to depend on the type of its valence electronic configuration. Thus, the adsorption behavior of Lr is studied by a newly developed method combining vacuum chromatography with surface ionization in a metallic column/ionizer of the ISOL.

In vacuum chromatography, adsorption-desorption processes of single atoms on a surface depend on the temperature of the chromatographic column and on the adsorption enthalpy of the species under investigation. On a metallic surface at high temperature, atoms are ionized during the desorption process from the surface; ionization efficiencies are described by the Saha-Langmuir (S-L) equation. If the loss of atoms due to adsorption on the surface of the column/ionizer is negligible, the ionization efficiency fully follows the equation. If a substantial fraction of all atoms remains adsorbed for extended times until their nuclear decay occurs, the apparent ionization efficiency becomes lower than the one for the case of negligible retention due to adsorption.

^{256}Lr($T_{1/2}$=27 s) was produced in the ^{249}Cf(^{11}B, 4n). Reaction products recoiling from the target were transported to the ionization site (ionizer) by an aerosol gas-jet transport system. The ^{256}Lr atoms were surface-ionized at different temperatures. Formed ions were mass-separated and then implanted into a Mylar foil of a rotating-wheel type α-particle measurement system (MANON) [3]. Ionization efficiencies of Lr were measured as a function of the ionizer temperature. At lower temperatures, the ionization efficiencies of Lr become lower than those expected from the S-L equation. This indicates that a significant fraction of the Lr atoms was adsorbed on the surface and decayed there. A Monte-Carlo simulation code for analysis of the behavior of Lr atoms in the ionizer has been developed based on the S-L equation and adsorption-desorption behavior on the surface.

Details for the investigations of atomic/chemical properties of the Lr atom will be presented at the conference. A perspective for application with transactinides will be also given.

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Presenter: Dr SATO, Tetsuya K. (JAEA, Ibaraki Univ.)

Contribution Type: Contributed talk

ID 96

Decay studies of heaviest nuclei: new reach with digital electronics

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Presently, the superheavy elements up to Z=118 are known. The heaviest known nuclei are produced in $^{48}Ca^{+}$ actinide reactions and are located closest to the predicted island of stability. In this region, fission is strongly retarded due to the nuclear structure which is predicted to form a closed shells (~magic numbers) at Z=114 and N=184. Presently, still no precise information on the extension and on the location of the center of the island has been obtained. While low production rates contribute to this problem, they are not solely responsible for this. Rather, this is also related to experimental limitation of commonly applied techniques for the detection and identification of the radioactive decay of superheavy nuclei. Most often, setups are sensitive for alpha- and spontaneous fission-decaying nuclei with half-lives roughly between several μs up to a few hours at most. Thus, the identification of the decay of nuclei (in their ground or isomeric state) with half-lives outside of these limits and via other modes of nuclear decay is challenging at best using standard experimental data acquisition (DAQ) methods. The lower half-life limit can be significantly decreased by using fast digital electronics, which gives access to more short-lived nuclei, and at the same time – by providing enhanced information on decays appearing as unwanted background – allows extending the correlation time windows, thus increasing the sensitivity also for more long-lived decays.

Since 2011 when digital electronics have been implemented at the gas-filled separator TASCA, many experiments dedicated to spectroscopy and chemistry of heavy nuclei and nuclear reactions were performed [1-7]. The scientific outputs of these experiments greatly benefited from the use of a digital electronics system.

In this talk, I will present results of the various TASCA experiments on the studies of both physics and chemistry properties of the heaviest nuclei performed with fast digital electronics.

Contribution Type: Invited talk

ID 98

Spontaneous fission studies for neutron-rich Fm and Lr isotopes

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Nuclear fission plays essential roles in the stability and lifetime of superheavy nuclei (SHN) and reaction probabilities of fusion, fusion-fission, and transfer channels in synthesizing the heaviest nuclei. These properties depend on the structure of potential energy surfaces around the fission barrier and its dynamical changes during the fission or the fusion processes, which can be investigated through detailed experimental studies of fission. In this work, we focus on the spontaneous fission of neutron-rich Fm and Lr isotopes. The spontaneous fission of those nuclei was studied more than 30 years ago at LBNL and LLNL using a minute amount of ^{254}Es target and an off-line isotope separator. They discovered the striking phenomenon of the sudden change of fission-fragment mass distributions from asymmetric to symmetric between^{256}Fm and ^{258}Fm and between ^{256}No and ^{258}No [1]. Although it is very interesting to clarify the mechanism of this phenomenon, more detailed experimental study has not been performed so far, because there has been no experimental facility at which fission studies can be performed using an ^{254}Es target. In 2017, we have obtained a minute amount of ^{254}Es material from ORNL, and started spontaneous fission studies at the JAEA tandem accelerator facility using an on-line isotope separator (ISOL). We successfully observed the spontaneous fission of mass-separated ^{256}Fm and ^{258}Fm produced in the ^{18}O + ^{254}Es multinucleon transfer reaction, and confirmed the previous results [1]. In addition, the spontaneous fission of mass-separated ^{259}Lr produced in the ^{248}Cm(^{15}N, 4n) reaction has been measured with mass and energy resolutions better than the previous ones [2]. Results of data analysis will be presented, and new insight into the fission mechanism observed in this neutron-rich heavy actinide region will be discussed.

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Presenter: Dr ASAI, Masato (Advanced Science Research Center, Japan Atomic Energy Agency)

Contribution Type: Contributed talk

ID 99

Nuclear Spectroscopy of Superheavy Nuclei

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Lund University

Detection technology, data processing, and various data analysis tools for superheavy element studies have advanced considerably during recent years. This has allowed for the first multi-coincidence high-resolution spectroscopy experiments along the decay chains of the heaviest man-made isotopes.

The impact of this type of experiments on the isotopic assignment of decay chains as well as the search for the island of stability will be discussed, with reference to nuclear structure considerations.

Contribution Type: Invited talk

ID 100

STATUS OF THE FLNR SHE-FACTORY

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FLNR JINR

The construction of the Factory of Superheavy Elements (SHE Factory), including a new experimental hall, is under completion. The Factory incorporates the new heavy-ion DC-280 cyclotron - its central device - that allows the production of beams of accelerated ions with masses A=10–100 and intensities up to 10 pμA ($6 \cdot 10^{13}$ s^{-1}), new separators and detectors. The main studies to be performed at the SHE Factory:

1. Experiments at extremely low (σ<100 fb) cross sections:
   - synthesis of new SHE in reactions with ^{50}Ti, ^{54}Cr;
   - synthesis of new isotopes of SHE;
   - study of the decay properties of SHE;
2. Experiments requiring high-statistics data:
   - nuclear spectroscopy of SHE;
   - study of the chemical properties of SHE.

On 26 December 2018, the first beam of accelerated ions was produced at the DC-280 cyclotron. This accomplishes one of the most important stages of the launch of the Factory. Experimental set-ups will be installed in three radiation-isolated caves with the total area of 1,500 m^2. In combination with the new gas-filled recoil separator DGFRS-II, the luminosity of the experiments at the SHE Factory will increase by some 50 times. Synthesis of new elements 119 and 120, which are the first elements of the eighth period of the Periodic Table, will be one of the key objectives of the Factory.

Contribution Type: Invited talk for the symposium

ID 101

Paneth and Elements: Insights and Misunderstandings

RUTHENBERG, Klaus

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”A chemical element is a substance the entire atoms of which contain the same nuclear charge.” This definitory statement (which equals the official description by the IUPAC since 1921) can be found in a paper by the eminent Austrian (later British) chemist Friedrich Paneth from 1920.

The Danish historian Helge Kragh writes: “Paneth's new definition of an element had roots going back to Lavoisier and it remains the one accepted even today”. At various other places in the literature, Paneth is similarly mentioned as the originator of the modern definition, though it is not always clear, which part of Paneth´s statements on the elemental status is addressed.

In the present paper, the influence of Paneth´s statements on the early IUPAC decision is investigated in more detail. I discuss the received view particularly before the background of Paneth´s well-known “Königsberg” lecture from 1931, in which he presents an elaborated dualist element interpretation. I will demonstrate that insights and misunderstandings revolve around the following aspects: the atomistic conception of chemical elements; atomic numbers as chemical properties; the dualist understanding of the notion “element”.

Selected sources

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Contribution Type: Invited talk for the symposium

ID 103

SURFACE FUNCTIONALIZATION TOWARDS NIHONIUM HOMOLOGS ADSORPTION STUDY

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Gas chromatography nowadays is the most commonly used approach to investigate the chemical properties of superheavy elements [1]. This technique allows for the transfer of recoils from the target chamber to the detector setup within several seconds, which is crucial in terms of the short half-lives of the investigated nuclides. The next step is adsorption of the element of interest on a detector surface according to its temperature and/or the surface composition. The main decay modes of superheavy nuclides in the vicinity of the island of stability are α particle emission and spontaneous fission (SF). Thus, Si-detectors are used to register α decay chains, usually terminated by SF [2]. Because the surface composition can facilitate the adsorption, there were experiments carried out with SiO_2 coated [3], metal (gold) [3] and nonmetal (selenium) [4] coated detectors. The long-term focus of our group is to modify the detector surface with organic compounds, selective to either indium or thallium as homologs of nihonium. Two approaches have been considered. One of them is the physical adhesion of polymerized ionic liquids (ILs) either on a flat glass surface or inside a PTFE tube. It has been shown that such a layer is not porous and still retains the properties of a nonpolymerized IL. For example, trivalent thallium was successfully extracted in solid-liquid phase experiments. Another idea is to chemically graft a specific organic molecule onto the Si surface. Again, an IL has been chosen to be used in the surface functionalization experiments. However, all the ILs tested by our group are sensitive only to trivalent thallium within a wide range of HCl concentrations. Nevertheless, in order to develop a surface for monovalent thallium adsorption, a conventional extractant molecule was grafted. Results obtained in all of the above experiments will be presented.

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Presenters:

Dr TERESHATOV, Evgeny (Texas A&M University); Prof. FOLDEN, Charles (Texas A&M University)

Contribution Type: Poster

ID 105

Laser spectroscopic investigation of the heaviest elements

RAEDER, Sebastian

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Chemical elements are classified by the number of electrons in the atomic shell which surround a nucleus with the same positive charge. The resulting wave functions of the electrons in the atomic shell finally define the physical and chemical behavior of the element. Laser spectroscopy is a versatile tool to unveil fundamental properties of the electron shell of an element such as excitation energies of atomic levels, the strength of optical transitions and electron binding energies. Furthermore, it enables the determination of subtle changes in the atomic level energies for different isotopes of the same element to infer properties of the center nucleus. The heaviest elements are of particular interest for laser spectroscopic studies as their electron shell is strongly influenced by electron-electron correlations and relativistic effects which affect the electron configuration and thus, the chemical behavior [1,2].

Elements up to fermium (Z=100) can be produced in nuclear reactors and can be investigated after chemical separation off-line. Heavier elements are only accessible through fusion-evaporation reactions at minute quantities and at high energies, hampering their optical spectroscopy. The challenges in laser spectroscopy of the heaviest elements will be discussed in view of the recent identification of optical transitions in nobelium (Z=102), observed in a pioneering experiment employing the **RA**diation **D**etected **R**esonance **I**onization **S**pectroscopy (**RADRIS**) technique [3]. With this technique the identification and characterization of several atomic transitions in nobelium was possible for the first time, leading for example to an accurate determination of the first ionization potential of nobelium. Measurements of an atomic transition in the isotopes $^{252-254}$No as well as resolving its hyperfine splitting in ^{253}No gave access to nuclear moments and differential charge radii.

For the future investigation of the atomic structure of the heaviest elements the extension of the RADRIS method towards even heavier elements is one direction. Complementary, new techniques such as laser spectroscopy in the super-sonic gas jet behind a gas stopping cell are being developed [4] for laser spectroscopy with higher spectral resolution. The present statues of laser spectroscopic studies will be reviewed and perspectives for experiments on superheavy elements will be discussed.

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Contribution Type: Invited talk

ID 107

Direct mass measurements of mendelevium isotopes in the vicinity of the N=152 deformed shell-closure

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In the initial phase of the SHE-Mass project at RIKEN, we have successfully measured masses of a wide variety of heavy/superheavy nuclei [1,2,3]. They were produced by fusion-evaporation reactions as well as transfer reactions. The reaction products were separated by a gas-filled recoil ion separator GARIS-II [4] at RIKEN and were transported to a cryogenic gas cell installed at the GARIS-II focal plane. At the gas cell, high-energy radioactive ion (RI) beams were thermalized and converted to low-energy RI beams by means of radio-frequency ion guide techniques. The continuous RI beams extracted from the gas cell were trapped in the first ion trap system, transported to downstairs as a bunch, re-trapped and cooled in the second ion trap system, and injected into a multi-reflection time-of-flight mass spectrograph (MRTOF) to make precision TOF measurement to determine their masses. The typical mass resolving power of the MRTOF was ~150,000 within their TOF of 6~ms or less.

Among them, in particular, masses of mendelevium (Z=101) isotopes in the vicinity of the N=152 deformed shell closure have been directly measured for the first time [3]. From those masses, the shell gap parameters for mendelevium and lawrencium at N=152 were evaluated and compared with theoretical predictions, where macroscopic-microscopic mass models, FRDM12 and WS_4^{RBF}, reproduced the experimental trends well. In addition, using the measured masses as anchor points for alpha decays, we could extend known-mass nuclei to the neutron-deficient side up to meitnerium (Z=109).

In the presentation, the detail for the measurements and results will be presented.

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Presenter: Dr ITO, Yuta (JAEA)

Contribution Type: Contributed talk

ID 108

Gas-filled recoil separator RITU, new dawn seen in the near future

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An extensive upgrade program is ongoing at the Jyväskylä Accelerator Laboratory JYFLACCLAB. The aim of this program is to increase the accelerated ion-beam intensities, which would allow using various heavy-ion induced reactions with small production cross sections. The new HIISI ECR-ion source and the upgrade of the JYFL cyclotron K-130 central region (higher injection voltage) will help to reach this goal. The gas-filled recoil separator RITU [1, 2] will be upgraded as well to be able to take advance of these high intensities. RITU upgrades include the new focal plane detector setup, more proper shielding of the focal plane system, rotating target wheel system, renewed slit-systems in RITU and more diagnostics in the RITU beam line for easier beam tuning. The status of the upgrades and possible experimental program using both MARA [3, 4] and RITU separators in the wide-range of the nuclei including the superheavy will be presented.

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Presenter: Dr UUSITALO, Juha (University of Jyväskylä)

Contribution Type: Poster

ID 109

Covalency Driven Stabilization in the f-block

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10-coordinate cerium and berkelium structures have been synthesized utilizing 4-nitrophenyl terpyridine, nitrate anions and a water molecule, where these structures present a degree of covalency. This degree of covalency is not observed in the isostructural lanthanide and actinide complexes, alluding to the covalency present in the cerium and berkelium structures being potentially attributable to their more easily accessible tetravalent states. This further stabilization of elements containing this low oxidation potential could make this system useful for analyzing Super Heavy Elements (SHE) such as rutherfordium. Although rutherfordium is known to be most stable in its tetravalent state, it does have a less stable, yet accessible trivalent state. Furthermore, this system is known to be robust, making long-withstanding crystals of berkelium, in addition to providing mass spectrometry data, proving useful through solid and gas-phase experiments.

Presenter: Ms GAISER, Alyssa (Florida State University, Albrecht-Schmitt Group)

Contribution Type: Poster

ID 111

The status of mass identification of superheavy elements with FIONA

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The search for new elements has netted us six additions to the periodic table this decade, bringing the total to 118 known elements. These elements must be formed one-atom-at-a-time in complete-fusion evaporation reaction. Once formed, the atoms typically exist for just seconds or less before they decay into other elements. While we have made great progress in making and studying these elements, there is much that is still unknown, including detailed information about their nuclear structure, nuclear shapes, decay modes and chemical properties. Even information as basic as the proton and neutron numbers of the recently discovered elements have yet to be experimentally confirmed.

Recently, the Berkeley Gas-filled Separator (BGS) at the Lawrence Berkeley National Laboratory (LBNL) was coupled to a new mass analyzer, FIONA. The goal of BGS+FIONA is to provide mass number separation and to transport nuclear reaction products to a shielded detector station on the tens of milliseconds timescale. These upgrades will allow for direct A and Z identification of i) superheavy nuclei such as those produced in the ^{48}Ca + actinide reactions ii) new actinide and transactinide isotopes with ambiguous decay signatures such as electron capture or spontaneous fission decay and iii) products from chemical reactions. In addition, we will be able to perform spectroscopy measurements on the heaviest nuclei or dive into determining chemical reaction rates.

Here we will present recent results from the FIONA commissioning and first scientific experiments, including mass-number measurements of superheavy nuclei and studies on the nuclear structure and chemistry of transactinide elements.

Presenter: PORE, Jennifer (LBNL)

Contribution Type: Invited talk

ID 113

Ion source development for the measurement of the ionization potential of superheavy elements (Z>= 104)

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The ionization potential (IP) is a fundamental atomic property of each element, which strongly influences its chemical behavior. Quantum chemical methods are used to predict the IP and the electronic shell structure. These theoretical calculations are of particular interest in the region of superheavy elements, where relativistic effects, which scale with Z^2, become increasingly important. While elements until Fm can be obtained in reactors, heavier elements can only be produced by means of particle accelerators. The limited production rates make the experimental determination of IPs for the heaviest elements difficult. Only recently, the measurement of the first ionization potentials of the heaviest actinides on a one atom-at-a-time scale was reported by Sato et al. [1], and for No also by Chhetri et al. [2]. In [1] the IP of the heaviest actinides were deduced from the ionization efficiency in a hot tantalum cavity, which is given by the Saha-Langmuir equation. The next heavier element and first superheavy element is rutherfordium (Rf). Its production rate is substantially smaller than that of Lr. In addition, the IPs are increasing in the early transactinide series [3]. Thus, the surface ionization efficiency decreases and further reduces the number of expected events compared to Lr. To overcome the limitations of surface ionization, we propose to investigate, if the surface ion source can be substituted by a forced electron beam induced arc discharge (FEBIAD) ion source [4], designed to ionize elements with higher IP. A FEBIAD type ion source is already commonly used at CERN-ISOLDE for the efficient extraction of radioactive ion beams [4]. While FEBIAD ion sources allow ionizing species with elevated ionization potential, the technique is more complex, and new obstacles have to be overcome. In contrast to surface ionization, the CdI_2 aerosol particles, used as carrier in the gas jet, are partially ionized. It needs to be ensured that the ion load does not exceed the limits for efficient operation. Due to the expected refractive nature of Rf, the ion source must be operated at very high temperatures, exceeding the typical operation temperatures of 2200°C. In addition, a procedure for the derivation of the ionization potentials from ion source parameters needs to be established. The latter could be achieved by extrapolation of the cross section curve plotted versus electron energy [5], or by comparison of efficiency curves to theoretical models. Besides theoretical predictions, our measurement campaign starts with the derivation of noble gas ionization potentials, to characterize the ion source, and extends to experiments using the lighter homologues of Rf and the aerosol carrier CdI_2.

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Presenter: Mr BALLOF, Jochen (Univ. Mainz / CERN)

Contribution Type: Poster

ID 114

Super heavy nuclei studied using heavy actinide targets and fast digital detection systems

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More than fifty super heavy nuclei as well as five new chemical elements have been synthesized in fusion reactions between ^{48}Ca beams and radioactive actinide targets over the last twenty years. The half-lives as well as alpha-decay energies of these new isotopes show a pattern of significant increases in stability as a function of increased neutron number, indicating that the shores of the long sought Island of Stability have been reached [1,2].

Five heaviest elements, from *Z*=114 flerovium to *Z*=118 oganesson, have been synthesized using actinide target materials from Oak Ridge National Laboratory (ORNL) [3]. New developments at ORNL in the production of actinide materials for super heavy element research include experiments on enhanced production of Z=97 ^{249}Bk, previously used for the synthesis of element *Z*=117 tennessine [4,5], and advances in stable isotope separation technology with potential application for radioisotope separation. The latter could lead to new isotopes for research on super heavy nuclei, such as enriched ^{251}Cf ($T_{1/2}$=898 years). This would allow exploration the reaction between ^{251}Cf and an intense ^{58}Fe beam [6], with the potential to synthesize the N=184 isotone ^{308}124 and discover three new elements with atomic numbers *Z*=124, 122 and 120.

Results of experiments at the Dubna Gas Filled Recoil Separator (DGFRS, JINR, Dubna, Russia) using ORNL targets of mixed-Cf isotopes and an ORNL/University of Tennessee-Knoxville (UTK) digital detection system will be presented [7]. This detection system has improved discovery capabilities with respect to short half-lives and lower energy thresholds. The mixed Cf targets used in these experiments [7] were produced at the ORNL Radiochemical Engineering Development Center (REDC) and offer the potential to synthesize new heaviest nuclei ^{295}Og and ^{296}Og with ^{48}Ca as well as a new element 120 with ^{50}Ti beam. A similar digital data acquisition system based on XIA Pixie modules is now being tested during a search for element 119 at RIKEN, with ^{248}Cm target material and an intense ^{51}V beam.

Support through US DOE Contract DE-AC05-00OR22725 is acknowledged.

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Presenter: EZOLD, Julie G. (Oak Ridge National Laboratory)

Contribution Type: Invited talk

ID 115

Relativistic couple cluster investigations of atomic properties of the heaviest elements.

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Theory can provide important support at all the stages of spectroscopic experiments, from planning the measurements, through extracting the properties of interest from the data, and to the interpretation of the results and their comparison to theoretically predicted values. To this end, highly accurate calculations of atomic properties are needed. In order to be reliable, such calculations must include both relativistic effects and electron correlation on the highest possible level.

Relativistic coupled cluster is considered one of the most powerful methods for accurate calculations of properties of heavy elements. Two variants of this method are available. The single reference coupled cluster approach (SRCCSD(T)) is suitable for calculations of ground state properties in systems of single reference character. This approach can be used to obtain, for example, ionization potentials and electron affinities. The multireference Fock space coupled cluster method (FSCC) is particularly suited for calculations of excitation spectra and open shell systems. Both methods provide reliable high accuracy results and have strong predictive power. Depending on the properties and systems of interest, one can select the suitable method for the task, or use both approaches in a complementary manner.

A brief introduction to the two variants of the relativistic coupled cluster method will be provided and anew development for calculations of magnetic hyperfine structure constants will be presented. I will focus on recent successful applications of the coupled cluster approach to spectra, hyperfine structure, and other properties of the heaviest elements.

Contribution Type: Invited talk

ID 116

Accommodating the Rare Earths in the Periodic Table: A Puzzling History

THYSSEN, Pieter

KU Leuven

One hundred and fifty years ago, anno 1869, the Russian chemist Dmitrii Ivanovich Mendeleev (1834–1907) wrote down his *Attempted System of the Elements*. He classified all known chemical elements according to their atomic weight and chemical analogies. Seven obscure elements, however, remained outside the system. Among these were the rare-earth elements erbium, yttrium, cerium, lanthanum and didymium. Today, anno 2019, the lanthanides and actinides are still banished from the main body of the periodic table. Worse still, it remains unclear how to accommodate them properly.

In this talk, I sketch the puzzling history of the rare-earth crisis, and focus on the three main accommodation methodologies that have been used to find a home for the rare-earth elements: (1) the *homologous*, (2) *intraperiodic*, and (3) *intergroup* methodologies. I start with Mendeleev's failed attempts in the period 1869–1871 to accommodate the rare-earth elements as *homologues* of the other elements.

I then look at the work of Bohuslav Brauner (1855–1935), a Czechoslovakian chemist and close friend of Mendeleev, whose life aim was to accommodate the rare-earth elements in the periodic table. After discussing his so-called *asteroid hypothesis*, I briefly look at the spectroscopic research by the British chemist, Sir William Crookes (1832–1919), who introduced the idea of *meta-elements* as a way to deal with the rare-earth crisis. In Crookes' opinion, the rare-earth elements were not different elements, but different meta-elements of one and the same elemental group, much like nowadays the elements are known to occur in different isotopic forms. This led to the idea to cluster the rare-earth elements collectively in one case of the periodic system, according to an *intraperiodic* accommodation methodology.

I finally turn to the pioneering work of Henry Moseley (1887–1915) and Niels Bohr (1885–1962) in 1913. With the introduction of atomic numbers and Bohr's atomic model, chemists began to realize that the rare-earth elements formed a separate group which bore no resemblance to the other elements in Mendeleev's system. As a consequence, the homologous and intraperiodic accommodation methodologies were replaced by an *intergroup* one, as first advocated by Bohr in 1921. The placement of the rare-earth elements as a separate family *between* two groups became the preferred methodology in the twentieth century, and led Glenn Seaborg (1912–1999) to propose his *actinide hypothesis*.

I conclude that the gradual evolution from a homologous to an intraperiodic to an intergroup accommodation methodology went hand in hand with a growing detachment of the rare earths from the other chemical elements. I argue that the contemporary discussions have shifted from the accommodation of the rare-earth elements as a whole to the placement of lanthanum and lutetium in particular. I thus end with a brief discussion of the modern rare-earth crisis, and show how the biologist, Charles Janet (1849–1932), had already stumbled upon a solution in 1929 when he developed the intriguing *left-step periodic table*.

Contribution Type: Invited talk for the symposium

ID 117

The Cosmos in the Lab: Perspectives at GSI and FAIR

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The construction of FAIR is proceeding rapidly. The trench for the SIS 100 accelerator is almost complete, and the realization of the concrete shell advances. The components of the accelerators of the future facility are in production and are arriving progressively on the campus of the GSI Helmholtzzentrum for Heavy-Ion Research in Darmstadt, Germany. While the full science potential of FAIR can only be harvested once the new suite of accelerators and storage rings is completed and operational, some of the experimental detectors and instrumentation are already available and will be used a dedicated research program at GSI, exploiting also the significantly upgraded GSI accelerator chain. The program has started in the summer of 2018 and will continue with a few months of beam time per year. The progress of the FAIR realization and the status as well as prospects of science at FAIR will be presented.

Contribution Type: Invited talk for the symposium

ID 118

The heaviest nuclei and elements

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The entire almost 80-year history of the advance to heavy elements was directly associated with the emergence of the new possibilities (methods) of synthesis in nuclear reactions of various types. Synthesis of actinides in reactions of neutron capture, transition to transactinides via hot and cold fusion reactions, and synthesis of superheavy elements in reactions with Ca-48 are already well known. On the other hand, progress on this route was determined, to a large extent, by the possibility to deal with extremely small effects. Sensitivity of the experiment has always been of crucial meaning. On a very limited experimental basis, theoretical models have been developed from which, however, there followed predictions concerning the fundamental properties of nuclei at the very verge of their existence.

At present, the heaviest nuclei (two isobars) observed in the experiment have mass of 294. Respectively, the heaviest elements have atomic number 117 and 118. The observed decay properties of the heaviest nuclei bring to a conclusion that we still have not reached the limit of nuclear mass and charge. Definitely, there can exist nuclei with $Z>118$ and $A>294$. The superheavy elements have finalized the 7th period of the Mendeleev Table; their decay products down to Rf and Db are located in the region of transactinides. New nuclides are more stable than previously known isotopes of these elements produced in cold fusion reactions. It makes possible to study their chemical properties.

Chemistry of superheavy elements is of interest by itself. The expected changes in electronic structure of the superheavy atoms due to relativistic contraction of internal orbits result in variance of chemical behavior of the heaviest elements compared to their light homologues. According to the predictions of QED theory, at the beginning of the 8th row of the Table we rapidly approach the critical value of the positive nuclear charge at which the group difference in the chemical behavior of the elements vanishes. It is also possible that this effect is present in the already known SHE.

The talk considers further advance of research in view of construction and commissioning of new experimental complexes which are being developed in number of laboratories. Outline of the first experiments at the "SHE Factory" will also be briefly presented.

Contribution Type: Invited talk for the symposium

ID 119

Experimental programs using ^{254}Es at the JAEA tandem facility

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Experimental programs using ^{254}Es ($T_{1/2}$=276 days) at the JAEA tandem facility will be introduced. The isotope was produced at the High Flux Isotope Reactor (HFIR) of ORNL, and sub micro-g material was transported to JAEA in 2017. The main subject of the program is to study fission for fermium and heavier-element isotopes, by produce them in charged-particle induced reactions using ^{254}Es.

For the prompt fission measurement in ^{4}He + ^{254}Es, correlation between fission-fragment mass and total kinetic energy for ^{258}Md and its excitation energy dependence were measured. Similar data were also obtained in the spontaneous fissions for ^{256}Fm and ^{258}Fm. The results revealed the multi-modal features for heavy and neutron-rich nuclei and its sensitivity on excitation energy and fissioing nucleus. Planned fission measurement using multi-nucleon transfer reactions in ^{18}O + ^{254}Es in this year will be discussed, by showing the experimental setup and data taken in other target isotopes [1,2]. Furthermore, in-beam nuclear structure study and precise mass measurement for heavy- and neutron-rich nuclides will be promoted in the next ^{254}Es campaign.

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Contribution Type: Invited talk

ID 120

Random Probability Analysis of Super Heavy Nuclei

STOYER, Mark A.

for Dubna/LLNL/ORNL/VU Collaboration

During the last 18 years, six new elements have been discovered and confirmed and over 40 new isotopes have been synthesized in nuclear reactions using ^{48}Ca beams and actinide targets (^{237}Np, ^{239,240,242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk, ^{249,251}Cf) [1]. To attempt to produce the heaviest isotopes of element 118, new experiments were performed using ^{48}Ca projectiles and a ^{251}Cf (mixed isotope) target at the Dubna Gas Filled Recoil Separator (DGFRS) located in the Flerov Laboratory of Nuclear Reactions in Dubna. Progress on the production of ^{294}Og and heavier isotopes of element 118, cross-section measurements, and nuclear decay properties will be discussed. The probability that observed decay chains are due to random events occurring in the detectors or electronics rather than correlated decay chains, using the LLNL-developed method of Monte Carlo Random Probability analysis [2-3] will be discussed. Random probability analysis for ^{48}Ca + ^{239,240}Pu experiments was discussed at TAN15 in Japan and will be compared with other techniques for estimating such probabilities in super heavy element production reactions in which few decay chains are observed, and with the new Og analysis.

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Presenter: STOYER, Mark A. (LNNL)

Contribution Type: Poster

ID 121

Recent developments in the theoretical description of the heaviest elements including cluster decays

WARDA, Michał

Maria Curie-Skłodowska University, Lublin

Quest for the heaviest elements existing in nature is a fascinating challenge for nuclear physics. Last discoveries made at GSI, RIKEN and Dubna laboratories extended the chart of nuclides up to element Z=118 oganesson [1].

The super heavy isotopes live very shortly and decay through alpha emission or fission. The type of decay and its half-life are the basic observables in these nuclei. Planning future experiments requires theoretical estimation of stability in both channels. Half-lives for alpha emission can be deduced from Geiger-Nuttall law. To predict them one has to deduce alpha decay Q value from binding energies calculated in a reasonable theoretical model [2]. The stability against fission in this region exists only due to shell effects as no barrier in the potential energy is predicted in the liquid drop model [3]. Moreover, large energy level density makes shell effects change between isotopes in the region of superheavy nuclei. The fission barrier may take various heights and shapes. It may be symmetric, asymmetric or triaxial. In many nuclei, even two-humped structure exists. The shape of the fission barrier as well as inertia along the fission path must be determined to predict half-lives and fission fragment properties. Various approaches have been applied to this end both macroscopic-microscopic and self-consistent [4].

Each type of fission barrier leads to the creation of specific fragments. It was found that in some isotopes around ^{294}Cn asymmetric fragment mass distribution is expected [5]. Detailed analysis indicates that the mass of the heavy fragment is governed by the shell structure of the doubly magic ^{208}Pb. The mass separation between fragments is larger than in typical asymmetric fission in actinides. It is rather an equivalence of cluster radioactivity that is exotic decay observed in light actinides [6,7]. This theoretical prediction needs to be verified by experimental measurements of fragment masses that is not possible at the moment.

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Contribution Type: Invited talk

ID 123

The recent history and near future for fast digital detection systems in super-heavy element research

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A twenty year history of fusion reactions between ^{48}Ca beams and radioactive actinide targets has resulted in more than fifty super heavy nuclei, including five new elements. With increasing neutron number, spectroscopic observables show trends toward stability and support the conclusion of approaching to Island of Stability [1,2]. However, as a function of increased proton number, half-lives are becoming shorter and first motivated digital electronic systems being adopted for data acquisition in early Z=120 searches [3].

A recent history of digital detection systems developed by XIA/ORNL/University of Tennessee-Knoxville (UTK) for super heavy element research will be presented in the context of results of experiments at the Dubna Gas Filled Recoil Separator (DGFRS, JINR, Dubna, Russia) using Pu and ORNL targets of mixed-Cf [4-6]. This detection system has improved discovery capabilities with respect to short half-lives and lower energy thresholds. The ORNL Radiochemical Engineering Development Center (REDC) produced mixed-Cf target used in these experiments [6] is a material capable to synthesize new heavier nuclei ^{295}Og and ^{296}Og with ^{48}Ca as well as a new element with Z=120, when bombarded with ^{50}Ti beam. A similar digital data acquisition system based on XIA Pixie modules is now being tested during a search for element 119 at RIKEN, with ^{248}Cm target material and an intense ^{51}V beam. New developments for the systems will also be discussed.

Support through US DOE Contract DE-AC05-00OR22725 is acknowledged.

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Contribution Type: Contributed talk

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