SHE@TASCA

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Introduction

Exploration of the upper part of the nuclear chart has always been a difficult task, particularly for trans-actinide elements, known as superheavy elements (SHE), which likely never existed on the Earth, and their synthesis to make just a handful of atoms, or even just one - is a challenge!

The first superheavy element Rf (E104) was discovered in 1964 at Lawrence Berkley National Laboratory by bombarding ^{248}Cm with ^{16}O. Immediately the question came up about the chemical behavior of this newly synthesized element. Does Rf open the next series of d-elements? Since then studies on the chemical behavior of newly synthesized superheavy elements became fascinating and equally challenging experiment in parallel to the discovery of new elements [1]. Initially aqueous radioanalytical chemistry played the most important role to find rooms for elements 104, 105 (Rf and Db) in the Periodic Table. Similarities and differences with their lighter homologues were systematically investigated. Aqueous chemistry of Rf with chloro-, nitrate-, fluro-, sulfate- and other complexes were carried out and compared with Zr, Hf. Similarly, the position of E105 was confirmed comparing its aqueous chemical behavior with Nb and Ta.

Darmstadt Era and TASCA commissioning

In the mean time, in 1981 the Darmstadt era of SHE started with the discovery Bohrium (Z=107) by cold fusion reaction. The success of GSI continued through the cold fusion reactions till the discovery of Copernicium, Z=112 in 1996 using the SHIP separator. Focusing on chemical studies, a new device, popularly known as TASCA (TransActinide Separator and Chemistry Apparatus), was designed and built. The driving force for setting up the new device was mainly the gas phase chemistry. The emphasis was set on SHE produced in hot-fusion reactions. Production rates decrease sharply with increasing Z up to about Z=110 and then stay rather constant over Z=112-118, where they are predicted to be much lower. TASCA was designed as a gas-filled recoil separator with maximized transmission (efficiency) for transactinides (SHE; $Z \geq 104$) from hot-fusion reactions with actinide targets, in particular for chemical investigations of SHE, nuclear structure and nuclear reaction studies of neutron-rich trans-actinide nuclides. The TASCA operates either in the 'high transmission mode' (HTM) or in the 'small image mode' (SIM). The transmission efficiency of HTM mode is about 60%. TASCA can be applied efficiently for nuclear decay and nuclear reaction studies of neutron-rich nuclides of SHE synthesized in very asymmetric hot-fusion reactions. The combination of TASCA, highly efficient Focal Plane Detector, Recoil Transfer Chambers (RTC), Rotating wheel On-line Multidetector Analyzer (ROMA) further increases the efficiency. It was declared in GSI report in 2008 that the TASCA as a whole is the most versatile and highest efficient instrument in SHE research worldwide [2].

Production of SHE at TASCA

Since then numbers of path breaking experiments have been carried out using TASCA pre-separator by the international collaboration known as "TASCA Collaboration" led by SHE Chemistry Group at GSI Darmstadt. The most noteworthy experiment so far at TASCA is the independent confirmation of new element 117

synthesized through $^{48}Ca + ^{249}Bk$ reaction, which immediately drew attention of the peer community [3]. The PRL paper [3] was amongst the top ten most popular paper in 2014 as declared by APS. The TASCA collaboration identified two decay chains comprising seven α decays and a spontaneous fission. It was decisively confirmed that both α decays came from the isotope $^{294}117$ and its decay products. During this experiment long-lived isotope, ^{270}Db was discovered whose half-life was determined as 1 h. The long-half life raised high hope for discovering the "island of stability" in future.

In fact TASCA collaboration performed 5 weeks (2011) and 5 months (2012) long hunts for discovering elements 120 and 119 using $^{50}Ti + ^{249}Cf$ and $^{50}Ti + ^{249}Bk$ reactions respectively. Another noteworthy experiment was, production and decay of element 114 [4]. The fusion-evaporation reaction $^{244}Pu(^{48}Ca, 3\text{-}4n)^{288,289}114$ was studied. Total thirteen decay chain was observed in one month long experiment, of which 5 chains were assigned to the 3n channel, the others were assigned to 4n channel. New nucleus ^{277}Hs was discovered in the 3 n channel. Upgrades of TASCA performed in 2010 allowed even to increase the sensitivity by factor 5

SHE chemistry at TASCA

Besides successful production of SHE elements and discovering new isotopes, TASCA collaboration also performed many state-of-art chemistry experiments. A gas chromatography experiment on Fl at TASCA was conducted earlier. $^{288,289}Fl$ was produced using the reaction channel $^{244}Pu(^{48}Ca,3/4n)$ [5]. Two COMPACT detectors connected in series were used of which the first detector was kept at room temperature while a temperature gradient was applied to the second detector. The use of two detectors allowed the detection of species in a wide volatility range – from the non-volatile Pb, the nearest homolog of Fl, to the noble gas Rn. Distributions of Pb, Hg, and Rn in two detectors were compared. The observed behavior of Fl in the chromatography column is indicative of Fl being less reactive than Pb. Also evaluation of the adsorption enthalpy on gold demonstrated the metallic character of Fl. TASCA combined with chemistry set up have demonstrated the ability for chemical studies on a one-atom-at-time level in a very broad range of volatility and reactivity.

To verify the possibility of studying the properties of carbonyl compounds of Sg and Hs, TASCA group synthesized CO complexes of short-lived W and Os isotopes, lower homologues of Sg and Hs [6]. $^{163,164}W$ and $^{170,171}Os$ were produced in the UNILAC accelerator, GSI. The short-lived nuclides were isolated in TASCA and guided to gas filled recoil transfer chamber (RTC). The ions were thermalized by CO/He gas mixture in RTC. During thermalization, they interacted with CO and yielded neutral carbonyl complexes.

Future Directions

The importance of exploring SHE chemistry can be understood from the recent minutes of G-PAC meeting of GSI-FAIR. Large numbers of proposals of excellent scientific merits were submitted for FAIR phase 0 experiment. Due to limited beam time availability in 2018-19, the G-PAC accepted few proposals. Interestingly the SHE chemistry experiment proposals, like first chemistry experiment of E113 were recommended without any cut in the proposed beam time.

Many hitherto unknown properties of SHE, to be qualified them as 'element', are to be explored in near future. Volatility and reactivity of Cn and Fl, organometallic compounds of Rf to Hs, redox reactions of Sg to Hs, atomic and ionic radii of SHE are few identified and challenging problems. It is a long search, an exciting one, and will be sketched in the lecture.

References

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