SYNTHESIS AND STUDY OF SUPERHEAVY ELEMENTS

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Results of experiments on the synthesis of superheavy nuclei in ^{48}Ca-induced reactions are presented. The experiments were carried out at the Flerov Laboratory of Nuclear Reactions (FLNR) Dubna heavy ion cyclotron U400 in the framework of a large collaboration: FLNR (JINR, Dubna, Russia), IAR (Dimitrovgrad, Russia), LLNL (Livermore, USA), ORNL (Oak-Ridge, USA) and Vanderbilt University (Nashville, USA).

Enriched isotopes of U÷Cf were used as targets. In the reactions studied in 2000–2011, decays of the heaviest isotopes of Rf÷Cn and isotopes of six new elements 113÷118 were observed. The discovery of the elements 114 and 116 has been recognized by the International Union of Pure and Applied Chemistry (IUPAC) in June 2011.

1. Introduction

First qualitative predictions of the position of an "island of stability" of superheavy elements (SHE) were done after analyzing the level diagrams of heavy nuclei [1, 2].

As in recent times, present-day theoretical predictions on the next closed proton and neutron shells numbers vary strongly depending on the model. Following the well-known shells with Z=82 and N=126 (^{208}Pb), the shell correction amplitude has a maximum at Z=114, N=184 (spherical shells) in macro-microscopic (MM) models. An interesting consequence from these calculations was the revealing of a remarkable gap in the level density of deformed nuclei around N=162 (deformed shell). After calculations performed using the Hartree–Fock–Bogoliubov (HFB)-model or self-consistent relativistic models, the next closed spherical proton shell is predicted at Z=120 or 126 [3].

At the beginning of 70-th the discovery of superheavy elements seemed to be reachable in the closest future without serious problems. A large number of projectile-target combination have been studied in attempts to produce superheavy elements around predicted new nuclear shell closures.

Multifarious sophisticated physical and chemical methods were employed for the isolation and detection of superheavy elements. Among the studied in 70–80-th reactions, there were fusion reactions: ^{232}Th+^{86}Kr, ^{248}Cm+^{40}Ar, ^{248}Cm+^{48}Ca, ^{254}Es+^{48}Ca, and deep inelastic transfer reactions ^{76}Ge+^{238}U, ^{136}Xe+^{238}U, ^{238}U+^{248}Cm [4–8].

No evidence for the formation of superheavy nuclei has been obtained. Figure 1 shows the upper limits of superheavy elements production cross sections reached by the use of on-line recoil separators, fast on-line and off-line chemical techniques.

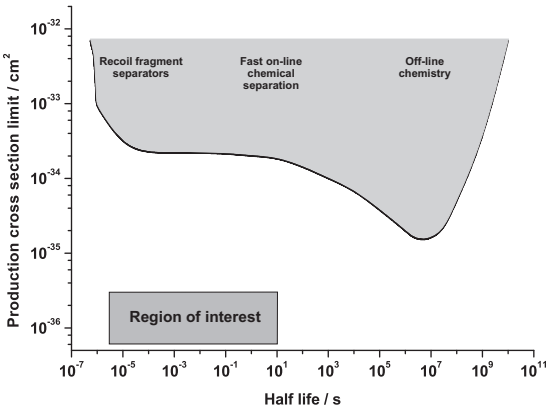

FIG. 1: Reached limits of superheavy elements production cross sections (envelope from [7]).

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First transfermium elements - Md–Sg have been produced in fusion reactions of U, Pu and later heavier targets up to Cf with ions from B to Ne. This type of reactions has been called "hot" fusion reactions.

The elements - Bh–Cn [9], were synthesized using the so called "cold" fusion reactions - fusion reactions between ^{40}Ar–^{70}Zn projectiles with magic nuclei ^{208}Pb and ^{209}Bi. Compound nuclei produced in this type of reactions have a minimum excitation energy compared with other target-projectile combinations [10], giving a substantial rise in the survival probability. But, as it has been found out later [9], the overall production cross-sections of evaporation residues, drastic decreased approximately by a factor of 3 with the increase in Z of a compound nucleus per unit charge. Figure 2 shows the production cross-sections of transfermium nuclei in "hot" and "cold" fusion reactions.

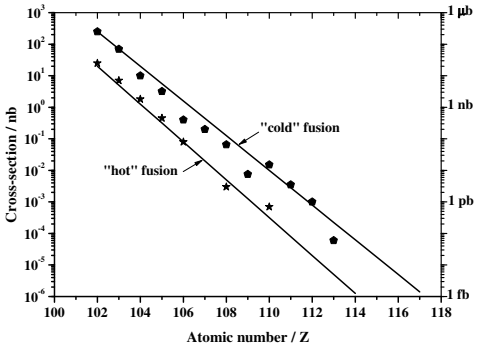

FIG. 2: Production cross-sections for "hot" and "cold" fusion reactions.

During 2003–2008, the RIKEN group (Japan) performed an experiment to synthesize element 113 in a ^{209}Bi+^{70}Zn reaction using the gas-filled separator GARIS [11]. The beam-on-target time amounted 7477 h and total accumulated dose of ^{70}Zn projectiles was $8.48{\cdot}10^{19}$. Two observed α-decay chains were assigned to the subsequent decays from ^{278}113. The production cross section corresponding to these two events was deduced to be 23^{+30}_{-15} fb (!).

It seems to be, the natural limit for production of superheavy elements in "cold" fusion reactions had been reached in this experiment.

The progress in development of accelerator technic, especially that, of ion sources, new data on reaction mechanisms and on properties of transactinide nuclei obtained during past 20 years allowed one to return by the end of 90-th to the use of double magic nucleus ^{48}Ca for the synthesis of superheavy elements.

2. Experimental approach and set-ups

The expected half-lives of heaviest nuclei produced in fusion reactions of ^{48}Ca with neutron rich actinides can vary in a wide range: from a few μs up to tens of hours. The expected cross-sections are calculated to be of the order of picobarns (10^{-36} cm^2) (see 'Region of interest" on the Fig. 1).

Because of extremely low expected production cross-sections of superheavy elements, the cornerstone in the experiments was the production of a stable and intense ion beam of the rare and expensive isotope ^{48}Ca at a minimal material consumption [12].

The low energy ^{48}Ca^{5+}-beam from the external 14 GHz ECR-ion source was axially injected into the center of the U400 heavy ion cyclotron's chamber. In all experiments the accelerator was operated in continuous beam mode (DC). The long-term average ion beams intensity on the target was ~ 0.6 pμA.

The evaporation residues (ER) were separated in-flight from beam particles and other reaction products by the Dubna Gas-filled Recoil Separator (DGFRS) [13]. The separation efficiency of ERs from reaction Act.+^{48}Ca was estimated from preparatory experiments. It has been determined that about 35÷45% of ERs, produced with the ^{48}Ca projectiles could reach the separator's focal plane detector.

The background from a primary beam at the focal plane was eliminated by a factor of $> 10^{17}$ and target-like products of incomplete fusion reactions were suppressed by a factor of $> 10^5$. Due to high suppression factors, the direct implantation of ERs into the focal plane detector was possible.

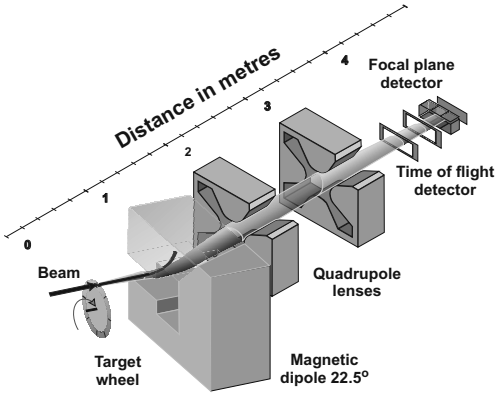

FIG. 3: Layout of the gas-filled recoil separator.

TABLE I: Targets and experimental conditions in irradiations Act.+^{48}Ca.

Target	Excitation energy (MeV)	Beam dose (10^{19})	ERs
^{233}U	32.7÷37.1	0.7	no events
^{238}U	29.3÷41.9	1.8	^{282,283}Cn
^{237}Np	36.9÷41.2	1.1	^{282}113
^{242}Pu	30.4÷47.2	1.8	^{286,287,288}114
^{244}Pu	29.8÷54.7	3.0	^{287,288,289}114
^{243}Am	38.0÷46.5	3.0	^{287,288,289}115
^{245}Cm	30.9÷44.8	2.6	^{290,291}116
^{248}Cm	31.2÷41.1	3.0	^{292,293}116
^{249}Bk	32.9÷41.1	4.4	^{293,294}117
^{249}Cf	26.6÷36.1	4.1	^{294}118

In the focal plane of the separator a system of multi-wire proportional chambers (TOF-detectors) and silicon position-sensitive stop and backward detector arrays were installed for the registration of ERs and their decays.

The signals from the TOF detectors were used both, for measurement of the recoils velocity and for distinguishing decays of the previously implanted nuclei (anticoincidence), from arriving ions signals (coincidence).

The time window for measuring decay chains could be widened up to several hours. A special "chopper" switched out the beam after a hardware request with selected parameters, coming from the data tacking system, allowing practically background free detection of correlated decays with a long half-life at the absence of a beam.

The data on energy, deposited in the stop- or/and backward detectors, time and position of appearing signals and auxiliary data were stored in a reference list mode. The analysis of events collected in an experiment has been performed to find generic decay links of the implants in certain time interval depending on the supposed half-lives.

3. Experimental results

The targets consisted of enriched isotopes of ^{233,238}U, ^{237}Np, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk and ^{249}Cf in a form of oxides deposited with a thickness of $\approx$ 0.35 mg/cm^2 on a 1.5-μm Ti foil.

The elementary targets in a shape of an arc segment were mounted on a disk, that was rotated at $\approx$ 2000 rpm. Experimental conditions: excitation energy ranges covered by targets, beam doses in 10^{19} and observed evaporation residues (ERs) are listed in Table I.

In reactions studied in 2000–2011 [14–16], decays of the heaviest isotopes of Rf ÷ Cn and 20 isotopes of 6 new elements with Z=113 ÷ 118 were observed among the products of complete fusion reactions involving ^{48}Ca projectiles and actinide targets U ÷ Cf. Decay properties of 45 new nuclide, produced in experiments with ^{48}Ca projectiles and actinide targets, are listed in Table II.

4. Studying chemical properties of superheavy elements

The investigation of chemical properties of superheavy elements is of fundamental significance. Some of the newly discovered isotopes have half-lives ranging from seconds to $\approx$ 1 d, times - reachable by radiochemical methods.

The most suitable for direct chemical studies (see Table II) are the isotopes of Cn: ^{283}Cn ($T_{1/2} \approx 4$ s) and ^{285}Cn ($T_{1/2} \approx 30$ s).

According to the atomic configuration in the ground state, Cn should belong to the 12-th group of the Periodic Table of the Elements as a heavier homologue of Hg, Cd and Zn. To what extent Cn is a homologue of Hg, depends on the so-called "relativistic effect" in the electronic structure of the superheavy atom.

TABLE II: Decay properties of the heaviest isotopes produced in Act.+^{48}Ca reactions [14–16].

Isotope	Decay mode	E_α (MeV)	$T_{1/2}$	N of events
^{267}Rf	SF	—	1.3 h	2
^{266}Db	SF/EC	—	22 min	1
^{267}Db	SF	—	1.2 h	1
^{268}Db	SF/EC	—	27.9 h	39
^{270}Db	SF	—	23.1 h	1
^{271}Sg	α/SF	8.54 ± 0.08	1.9 min	3
^{270}Bh	α	8.93 ± 0.08	1.0 min	1
^{272}Bh	α	9.01 ± 0.06	8.2 s	24
^{274}Bh	α	8.80 ± 0.10	0.9 m	1
^{275}Hs	α	9.30 ± 0.06	0.19 s	3
^{274}Mt	α	9.76 ± 0.10	0.45 s	2
^{275}Mt	α	10.33 ± 0.09	9.7 ms	1
^{276}Mt	α	9.70 ± 0.06	1.6 s	24
^{278}Mt	α	9.55 ± 0.19	7.6 s	1
^{279}Ds	α/SF	9.7 ± 0.06	0.20 s	26
^{281}Ds	SF	—	11.1 s	10
^{278}Rg	α	10.69 ± 0.08	4.2 ms	2
^{279}Rg	α	10.37 ± 0.16	0.17 s	1
^{280}Rg	α	9.75 ± 0.06	3.5 s	24
^{281}Rg	SF	—	26.3 s	6
^{282}Rg	α	9.00 ± 0.10	0.5 s	1
^{282}Cn	SF	—	0.8 ms	12
^{283}Cn	α/SF	9.54 ± 0.06	3.8 s	22
^{284}Cn	SF	—	0.1 s	19
^{285}Cn	α	9.15 ± 0.05	29.0 s	10
^{282}113	α	10.63 ± 0.06	73.0 ms	2
^{283}113	α	10.12 ± 0.09	0.1 s	1
^{284}113	α	10.00 ± 0.06	0.95 s	24
^{285}113	α	9.74 ± 0.08	5.5 s	6
^{286}113	α	9.63 ± 0.10	20 s	1
^{286}114	α/SF	10.19 ± 0.06	0.13 s	24
^{287}114	α	10.02 ± 0.06	0.48 s	16
^{288}114	α	9.94 ± 0.06	0.80 s	18
^{289}114	α	9.82 ± 0.05	2.6 s	10
^{287}115	α	10.59 ± 0.09	32 ms	1
^{288}115	α	10.48 ± 0.06	170 ms	24
^{289}115	α	10.31 ± 0.09	0.22 s	6
^{290}115	α	9.95 ± 0.40	16 ms	1
^{290}116	α	10.84 ± 0.08	7.1 ms	10
^{291}116	α	10.74 ± 0.07	18 ms	3
^{292}116	α	10.66 ± 0.07	18 ms	5
^{293}116	α	10.54 ± 0.06	61 ms	4
^{293}117	α	11.03 ± 0.08	14.5 ms	5
^{294}117	α	10.81 ± 0.10	77.5 ms	1
^{294}118	α	11.65 ± 0.06	0.89 ms	3

As it has been shown in [17], Hg atoms can be transported with a neutral carrier gas (e.g., He, Ne) to a distance of more than 30 m, with a velocity of up to 5 m/s. Therefore, investigation of Cn adsorption on metal surfaces has been undertaken. To produce the isotope ^{283}Cn the reaction ^{242}Pu(^{48}Ca,3n)^{287}114 $\xrightarrow{\alpha}$ ^{283}Cn has been used.

The chemical setup applied in these experiments (Fig. 4) was based on the thermochromatographic *in situ* volatilization technique (IVO) combined with the cryo-on-line detector "COLD" [18].

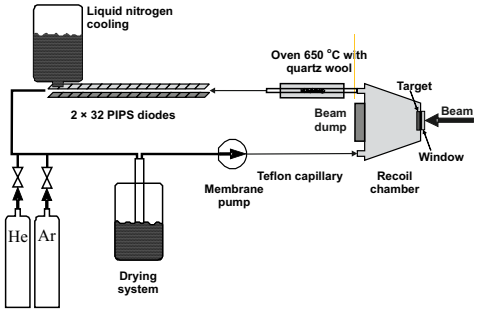

FIG. 4: Schematic experimental set-up used to investigate adsorption properties of Cn on a gold surface.

To the ^{242}Pu-target $^{\text{nat}}$Nd has been added to produce the α-radioactive Hg isotopes, which served to monitor the production and separation processes.

The recoil nuclei leaving the target stopped in a high-purity gaseous medium: He(70%)+Ar(30%). A self-drying closed gas loop system was developed to keep the amount of trace gases such as oxygen and water in this carrier gas mixture as low as possible.

The stopped nuclei were transported to detectors by means of a 8 m capillary tube . The total transport time from the reaction chamber to detectors was 3.6 s. This time is long enough for the decay ^{287}114 $\xrightarrow{\alpha}$ ^{283}Cn.

The detector array "COLD" consisted of 32 pairs of ion-implanted planar silicon detectors facing each other, forming a narrow chromatographic channel.

One side of the channel was covered with a 50 nm thick gold layer, deposited directly on the silicon detector surface. A temperature gradient was established along the detector array using a thermostat at the entrance and a liquid nitrogen cryostat at the exit, spanning a range from room temperature to -184^{o}C.

In control experiments α-particles from decays of isotopes of high volatile elements $^{181-188}$Hg (from ^{nat}Nd+^{48}Ca reaction) and ^{219,220}Rn (descendants of transfer products) have been detected. Hg atoms are registered by the first detectors, and decays of the chemically neutral Rn atoms by last ones, which are at the lowest temperature.

During the runs [18, 19], experimental condition: gas flow rates and temperature gradients were varied.

One of the obtained thermochromatographic deposition patterns for ^{185}Hg, ^{219}Rn, and ^{283}Cn are depicted in Fig. 5 and represent a characteristic example for the gas chromatographic behavior of single atoms.

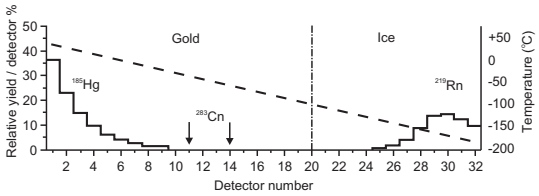

FIG. 5: Thermochromatographic deposition patterns of ^{185}Hg, ^{219}Rn, and ^{283}Cn.

The statistical analysis of the deposition behavior of ^{283}Cn (Fig. 5) revealed a standard adsorption enthalpy of element 112 on gold surfaces of $\Delta H^{Au}_{abs}(Cn) = 52^{+4}_{-3}$ kJ·mol^{-1} [18].

The observed enhanced adsorption enthalpy indicates a metallic-bond character involved in the adsorption interaction between Cn and Au.

By applying the estimated values for the sublimation entropy $\Delta S_{subl} = (106.5 \pm 2.0)$ J · mol^{-1}K, Cn can be presumed to have a boiling point of (357 ± 110) K. These values indicate that element 112 is considerably more volatile compared to its lighter homologues Zn, Cd, and Hg.

In experiment [19], aimed at the investigation of chemical properties of Cn rather unexpectedly, one decay chain was observed, which was unambiguously attributed to the decay of ^{287}114. Even more surprising was the observation of this decay chain on the detector 19, held at a temperature of -88 ^{o}C.

There were special thermochromatography experiments devoted to the element 114 [20]. From the observation of three atoms of element 114 adsorbed on gold surfaces of the COLD detector, its most probable standard adsorption enthalpy on gold was determined as $\Delta H^{Au}_{abs}(E114) = 34^{+20}_{-3}$ kJ·mol^{-1}.

So, the experimental data point to "Hg-like" behavior of Cn and rather "noble gas like" behavior of the element 114. This observation is the first indication on the influence of relativistic effects on properties of superheavy atoms. This problem is fundamental for the modern chemistry. Experiments are in progress.

5. Summary and outlook

What can we learn from the analysis of the whole set of the data?

In reactions Act. + ^{48}Ca 20 isotopes of six new elements 113 ÷ 118 have been produced and among their decay products 25 heaviest isotopes of the known elements Rf ÷ Cn identified. Figure 6 shows the "north-east" corner of the chart of the experimentally investigated nuclides.

The discovery of the elements 114 and 116 has been recognized by the IUPAC in June 2011 [21]. *The IUPAC/IUPAP Joint Working Party (JWP) on the priority of claims to the discovery of new elements 113–116 and 118 has reviewed the relevant literature pertaining to several claims. In accordance with the criteria for the discovery of elements previously established by the 1992 IUPAC/IUPAP Transfermium Working Group (TWG), and reinforced in subsequent IUPAC/IUPAP JWP discussions, it was determined that the Dubna-Livermore collaborations share in the fulfillment of those criteria both for elements Z = 114 and 116. A synopsis of experiments and related efforts is presented.*

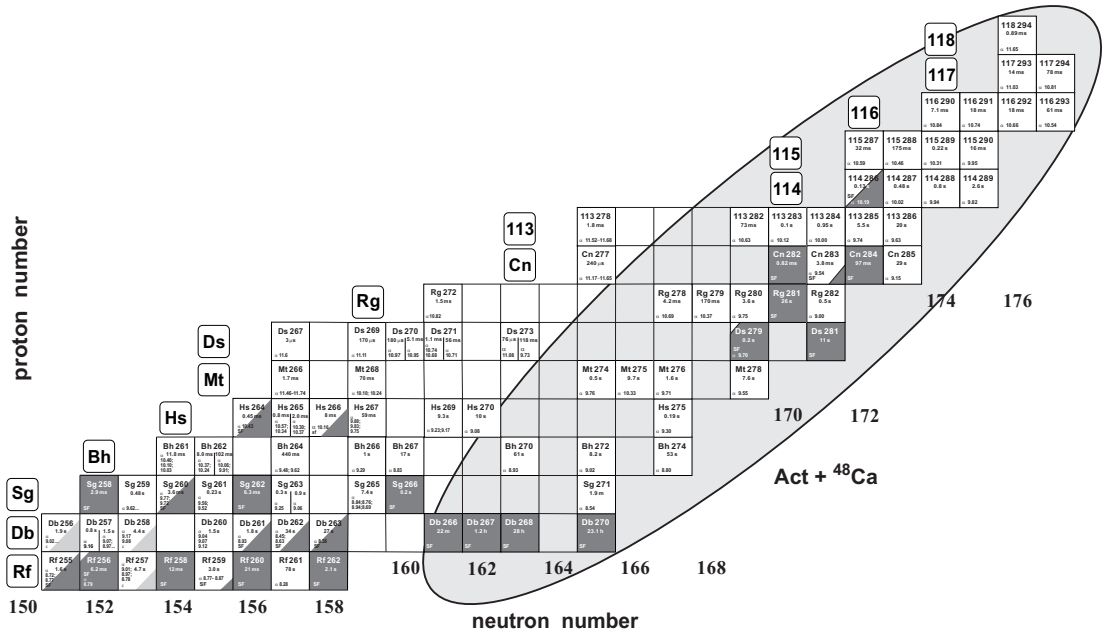

FIG. 6: The "north-east" corner of the chart of the nuclides.

In reactions with ^{48}Ca at a bombarding energy close to the Coulomb barrier the maximum yield for 3n- and 4n-evaporation channels has been observed. Products of evaporation channels accompanied by the emission of charged particles (protons, α-particles) have been not observed.

For all events of sequential α-decays the energies and decay probabilities obey the basic rule of Geiger—Nuttall (e.g. in the form [22]), which connects the α-decay energy Q_α and the half-life T_α and imply decays of nuclei with large atomic numbers $Z = 110$ – 118.

According to existing systematics, spontaneous fission events with TKE ~ 200 MeV are related to the decay of considerably long-lived nuclei with $Z \geq 104$ which for one's turn are "issues" of even heavier nuclei.

Comparing properties of "light" isotopes, produced in "cold" fusion reactions [9, 11], with those of "heavy" ones, produced in Act. + ^{48}Ca reactions (Table II), one can see, that addition of several neutrons leads to a significant increase in lifetimes (Table III). These data indicate on the presence of a neutron shell at higher neutron numbers.

TABLE III: Decay properties of the heaviest isotopes produced in Pb,Bi + ^{48}Ca and Act.+^{48}Ca reactions.

"Light" isotope	$T_{1/2}$ (ms)	Δn	"Heavy" isotope	$T_{1/2}$ (s)	Gain
^{269}Ds	0.2	14	^{281}Ds	11.1	$6 \cdot 10^4$
^{272}Rg	3.8	9	^{281}Rg	26.3	$7 \cdot 10^3$
^{277}Cn	0.7	8	^{285}Cn	29.0	$4 \cdot 10^4$
^{278}113	1.8	7	^{285}113	20.0	$1 \cdot 10^4$

Comparing the half-lives of even-even most long living isotopes ^{284}Cn - $T_{1/2} = 0.1$ s, ^{288}114 - $T_{1/2} = 0.8$ s, ^{292}116 - $T_{1/2} = 18$ ms and ^{294}118 - $T_{1/2} = 0.9$ ms, one can suppose, that $Z = 114$ is probably a proton shell.

Similar conclusion can be drawn after analyzing production cross-sections of superheavy isotopes [14–16] (see Fig. 7).

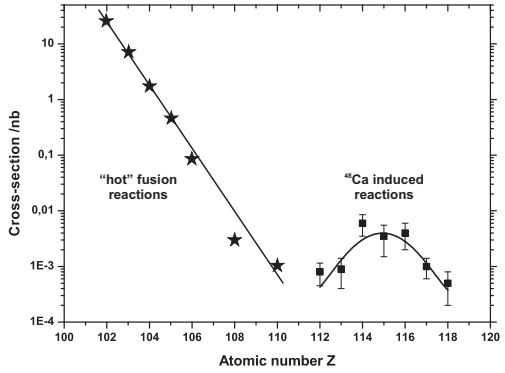

FIG. 7: Measured excitation functions maxima of xn-evaporation channels of Act.+^{48}Ca reactions.

Regardless of the facts that there are interplays of odd-even effects, mass-asymmetries in entrance channels, differences in formation and survival probabilities of compound nuclei, the clear maximum in the vicinity of Z=114 is also an indication on the presence of a closed shell around this proton number.

There is also an indication, that this shell could be a spherical one. In the limits of the detector energy resolution all α-decays of ^{288}114 can be attributed to the decay from the ground state, which is populated after decay of the evaporation residue or after the α-decay of the parent nucleus ^{292}116. This can be compared with the decays of ^{277}Cn, which populate different levels in deformed (due to the neutron shell N=162) ^{273}110. Similar, in the two decays of ^{278}113 [11], observed α-transition differ by 0.15 MeV .

Relatively long half-lives of isotopes with Z = 108–114, obtained in ^{48}Ca induced reactions, open up new opportunities for the investigation of the influence of relativistic effects on chemical properties of superheavy elements.

Due to relatively long life-times on new isotopes, the experimental approach to their investigation can be changed – quasi-on-line mass separation or chemical separation can be employed. These methods have sufficient advantages in the effective target thickness (factor of ∼15) and in the beam acceptability.

6. Investigation of reactions perspective for the synthesis of SHE

The heaviest isotope, that can be used in reality as a target for the synthesis of SHE, is ^{251}Cf. The advance to isotopes of heavier, than Z=118 elements, requires using of heavier projectiles e.g. ^{50}Ti, ^{54}Cr, ^{58}Fe and so forth.

Three reactions, leading to the same compound nucleus – ^{302}120 (N=182) have been studied at the velocity filter SHIP (GSI, (^{238}U+^{64}Ni and ^{248}Cm+^{54}Cr) and DGFRS (FLNR, ^{244}Pu+^{58}Fe). No events which could be attributed to formation and decay of Z=120–isotopes were detected. The sensitivity of these experiments corresponded approximately to 0.4 pb for the detection of a single decay. The study of ^{249}Cf+^{50}Ti reaction started at the TASCA (GSI) gas-filled separator in autumn 2011.

The most neutron rich nuclide produced so far in ^{48}Ca induced reactions are ^{293}116 and ^{294}117. A step to more neutron rich nuclei could be done using the isotopes ^{250}Cm ($T_{1/2}$=9700 a) and ^{251}Cf ($T_{1/2}$=898 a). However, for the separation of these isotopes one needs special electromagnetic separators, which are yet not available.

Thus, the obtaining of nuclei close to the neutron N=184 shell in Act.+HI reactions requires studies of the reaction mechanisms, so as to determine optimal conditions and to provide realistic estimates of the probability of producing compound nuclei in such reactions. Another possibility is to look for reaction other than Act.+HI.

7. Reactions other than HI + Act

Reactions of ^{82}Se+^{208}Pb and ^{86}Kr+^{208}Pb were studied using the velocity filter SHIP at GSI with a sensitivity of ≈ 1 pb, but no events which could be attributed to the formation of isotopes with Z=116 or else 118 were observed.

A very attractive possibility could be the use of neutron-rich radioactive magic nuclei as beams, e.g. fission fragments ^{132}Sn ($T_{1/2}$=40 s); ^{133}Sb (2.5 min) and ^{134}Te (42 min), and of complementary fission fragments like ^{93}Kr ($T_{1/2}$=1.3 s).

Fusion reactions with stable nuclei, for instance ^{132}Sn+^{176}Yb could lead to compound nuclei with Z_{CN}=120 and N_{CN}=188. In reaction ^{226}Ra+^{93}Kr, compound nucleus with Z_{CN}=124 and N_{CN}=195, decaying down to the isotope $^{296}114^{182}$ (3n channel), could be formed.

In principle, the use of symmetric reactions between deformed nuclei like ^{150}Nd+^{150}Nd should also be considered. In this case the effect of orientation of interacting nuclei in a touching point can play an important role in the rise of compound nucleus formation cross-section.

However, from the experimental data it is known, that the increased Coulomb repulsion in symmetric reactions, will enhance the quasi-fission channel and thus hinder the formation of a compound nucleus. As long as calculations of these limitations are very uncertain, it seems reasonable to estimate them using test reactions with known nuclei.

In this connection first experiments aimed at the study of symmetric reactions - ^{136}Xe(^{136}Xe,xn)$^{272-x}$Hs and ^{136}Xe(^{124}Sn,xn)$^{260-x}$Rf were conducted radiochemically at the FLNR and using LISE-III spectrometer at GANIL. In both cases the upper limit of only $\approx$ 20–100 pb has been reached.

8. Search for superheavy elements in nature

The possibility to exist in Nature of elements heavier than ^{238}U depends on two determinatives: in the Universe should exist a mechanism leading to the formation of superheavy elements, and it is necessary that one of superheavy nuclides would have a lifetime comparable with the age of the Earth (of about $(4-5)\cdot 10^9$ y). The search for heavy elements in terrestrial samples, meteorites and in cosmic rays in 70's and 80's was one of the extensive experimental investigations.

When choosing the objects of such studies, it was assumed that the most stable nuclei were located in the vicinity of the closed shells Z=114 and N=184 (corresponding to the chemical behavior of Pb) [24].

In all experiments only upper limits of the superheavy element concentration in the studied samples have been determined. All this resulted in a pessimistic view on the possible existence of SHE in nature, and the searching experiments were practically stopped in the mid of 80-th.

The experimental data accumulated, and development of modern microscopic models during passed 30 years, simulated new approach to the search for perspective objects.

So, a noticeable increase in $T_{1/2}\alpha$ and $T_{1/2}SF$ may be expected in the region of nuclei with $Z \leq 110$ [14], which has not been yet looked for. Calculated half-lives $T_{1/2}$ of isotopes of elements 108 and 114 against spontaneous fission and α-decay, obtained in a MM-model [23], are shown in Fig. 8.

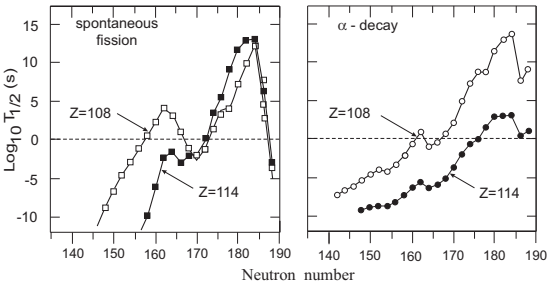

FIG. 8: Predicted half-lives $T_{1/2}$ of isotopes of elements 108 and 114 against spontaneous fission and α-decay.

Considering different nuclei as objects for such studies, it turns out that for element 108 - Hs[14], the chemical homologue of Os, the chances to be found in terrestrial samples could be favorable.

The search for rare decays may be undertaken with a raw metallic sample of Os, where atoms of Hs can be present. Spontaneous fission in an Os sample (up to 1 kg) can be registered by detecting multiple emission of prompt neutrons [25].

Such an experiment has been now running in the underground laboratory in Modane (France), protected by a 4000-m water-equivalent layer and it will be continued for several years.

Another possibility for choosing of objects, perspective for SHE search, can follow from the discovered high volatility of Cn and element Z=114. These elements can be gases (noble) at normal conditions – the boiling temperature of Cn is (360 ± 100) K. Thus one can look for SHE in heavy fractions of Xe production.

The problem of the existence of superheavy elements belongs to the must fundamental in natural sciences, because it affects nuclear and atomic physics, quantum chemistry, electrodynamic of strong fields, astrophysics, cosmology, and undoubtedly the efforts to solve it will be actively continued.

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