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Superheavy Chemical Elements (SHCEs)-Research Avenues

Mohammed Najmuddin Khan. M.Sc. M. Phil[1]

Principal Investigator MRP UGC SERO HYDERABAD.
Research Scholor, Gondwana University,MS.

DR RANJEET A MONDAL, PRINICIPAL & GUIDE[2]
Netaji Subash Chandar Bose College,
Mulchera, Gadchiroli Dist. MS.

Abstract:

Searching for new elements, either heavy, Superheavy and **Hyperheavy** (future elements) is still an outstanding object and not simply an attempt to increase number of rows/columns of periodic table . But it is a challenge to say, how many elements may exist? It is so good to coin the term "Hyperheavy[1] Elements[1] it is evident that presently the life span of SHEs is in progress in researches. At a particular stage this may not be treated as a continuation of progress in researches of SHEs but HHEs [Hyperheavy Elements]. The author authoritatively states that the half lives of few HHEs would be equivalent or greater than the half life of the universe with spontaneous emission. A few other HHEs would remind us of the SHEs. This research would prove to be of great use in the fields of medicine , nuclear and defence. Further, the expenditure that would be involved in this area of research, naturally or artificially would be very meager. These future HHEs would fulfill the needs of different fields compared to the elements that are used presently. Secondly, at what element with end the periodic table? Is synthesizing and getting new element nuclei, is only the ultimate method or searching those with high half lives and radioactive and may put them in the periodic table just after the Uranium- forming "Heperheavy series" with half-lives less or more than the universe? If yes, than any homologizes in between chemical, physical properties or arrangements of electrons in the strong electric field of the Nucleus? Nature of newly produce elements: Radio active on non-radioactive with the exclusively useful in medical and in nuclear developments. I expect some strong elements, afore said, found may some of them in known/unknown planets, nebulae or in 'Sun'. In this work author not discuss about HHEs but, focus on producing SHCEs by the chemical methods like Cold Fusion Reaction [CFR], Hot Fusion Reaction[HFR], significance of Single atom Chemistry, liquid phase chemistry and benefited with cyclotrons and accelerators [with sufficient beam energy], attached with gas filled chambers and detectors , covering wide range of angle. Specially focused on CFRs and HFRs: the present methods create research motivation in both, physics and chemistry research scholars.

Key Words:

HE : Heavy Elements
SHCEs : Superheavy Chemical Elements
HHCEs* : Hyperheavy Chemical Elements
HFR : Hot Fusion Reaction
CFR : Cold Fusion Reaction

1.Introduction:

Like the neutrons in an atom, nucleons in a nucleus – described by quantum mechanical laws-from closed shells called "magic numbers". At the magic proton or neutron numbers 20, 28, 50 and 82. But as SHCEs are introduced [synthesized] 126 and 184 were predicted to be the next shell closures. The term Superheavy element was coined for these

[1] First author insight

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elements. The half life of SHCEs varies mille to microseconds. Prediction of half life of these elements by different researchers is almost the same but the order of its magnitude is different. On the other hand if, naturally occurring SHCE are discovered then, its half life may approach the age of the universe or it also shows spontaneous emission like α -decay, β -decay and electron capture

Presently, production of SHCEs is based on laboratory synthesis, a chemical method. However a dramatic development are possible without technical limitations as proved with the recent experiments based on Cold Fusion Reaction [CFRs] and Hot Fusion Reactions [HFRs]. Few laboratories such as Gesellschaft für Schwerionenforschung, GSI, in Darmstadt ; Joint institute for Nuclear Research, JINR, in Dubna, done the synthesis of element 107 to 112, 114 and 116 respectively. Also Lawrence Berkely National Laboratory, LBNL, in Berkely reported for an element 118. Moreover, full range Nucleosynthesis in the laboratory was successfully observed by S.V.Adamenko, A.S.Adamenko and V.I.Vysotskii at 'Proton-21' laboratory, established in the year 1999, located in Kiev.

Addition to the Adamenko tri-men team, many other highly qualified specialists from the National Academy of Science, NASc, in Ukrine and the leading universities of Ukrine participated to uplift the synthesis methodology and work on par with the ' Electrodynamics Proton-21 laboratory' of Kiev.

In this work the author tries to create awareness to those research scholors who interested in Physical chemistry and nuclear physics.

2. **Synthesizing SHEs:**

Synthesis of Heavy and Superheavy Chemical Elements, from the technological point is very demanding and this requires the development of unique experimental methods, concentrating and reviewing all the existing techniques and components involved, selective and efficient separation procedures, sophisticated detection system of the nuclear decay of the separated species to get un-equivocal proof for the entire process.

2.1Experimental Techniques:

Error free experimental set-up demands the systematic literature survey, background knowledge regarding artificial production of elements/isotopes and chemical synthesizing, selecting the suitable target and projectiles and cyclotrons and accelerators, beam energy and time period. All these make possible to climb up the periodic table element by element.

In general, transuranic elements are always man-made. By the neutron capture in high-flux reactors and successive β^- decay and too short 'α'and fission half-lives of the heavier elements. During the above mentioned method, neptunium to californium can be produced. Since two heaviest species, ^{254}Es and ^{257}Fm, are available only in quantities of micrograms and picograms, respectively. To avoid such difficulties, intellectuals selected heavy-ion fusion reactions, the bombardment of heavy-elements target with heavy ions from a pre-selected accelerator.

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2.1Target selection:

As far as the selection of target is concerned, two important points are to be remembered. One, target should be thin, about or near the order of 1mg/cm^2: to avoid energy loss of the ion beam. Otherwise, energy distribution and fission product in-flight separations are wide and thus effected on the reaction mechanism: based on function of the beam energy.

2.3 Projectiles:

The basic principle is the distance selection in between the projectile and the target to get measuring excitation functions that yields as a function of the beam energy. Variable distance yields different functions. Secondly, knowing the properties of both, projectile and target- is the main step before the reaction, third is the selection of the coordinate system. Various projectiles and targets so far taken as the actinide targets- best suited projectiles are Neon-Calcium, for Lead (Pb) and bismuth target, calcium to krypton. Another example for symmetric combinations are tin plus tin up to samarium plus samarium.

3.0 Accelerators:

In order to produce heavy elements, first, cyclotrons are used. Countries like Berkely-California, Dubna-Russia, and Finland, Italy and Japan are in the race to produce new elements and upgrade the ion beam intensity. However, historically, Berkely-California used the first cyclotron for the production of heavy elements. And for the synthesis of SHCEs, they enhance the ion-beam intensity along with the D's-dia 300 and 400cm with code U300 and U400 respectively, aiming at the acceleration of ions as heavy as Uranium, named as HILAC(Heavy Ion Linear Accelerator) and SuperHILAC and UNILAC(Universal Linear Accelerator) in Germany.

Increasing beam currents is must, since synthesis of elements is decreased cross-section area. Still, this demand is continuous in order to deliver high currents at high ionic charge states. This high current, in turn, demand high resistance of the target (selection importance). The aforesaid countries, now working on the 'exchange of know-how' basis. All superheavy elements have extremely less half-lives(less than micro-sec) need good physical techniques and large area position sensitive detectors 'velocity filter: SHIP(Separator for Heavy-Ion reaction Products) developed at the UNILAC , had good techniques. During the synthesis method, the recoil stopping and utilization of ion-source are significant. Combined electric and magnetic fields are helpful to control the above deficiency. Recoil velocities and the lengths of separators both, determined the separation time ranging 1-2 μ sec. There are two recoil separators that have been developed. One, gas filled: while synthesizing, recoils and projectiles [slow reaction projectile and fast projectiles] and difference between these will calculate by using helium [filled in gas separator], to obtain maximum difference in rigidities observed in synthesis. Two, Wien-filter are use to determine the kinematics properties of fusion product. During the process, 'ionic charge states 'of the reaction product is an essential factor. Colorless light passed away escaped from a thin solid-state target into vacuum, is

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needed for high transmission. To get it, you can use additional magnetic or symmetric electric field. Best experimental set up example is SHIP (Darmstadt): A velocity filter used for heavy ion reaction product, Eleven meter long detector, 31cm dia target wheel and 450μg/cm^2 target thickness used to get reaction product in 2μ sec! we can increase efficiency also by adding and arranging secondary electron foil silicon detectors to observe radioactive decays or α-particles of the decay chain.

The SHIP is fully automated detector with respect to

- Switching of the beam as implanted residue detected
- Extremely small response time (say) 20μ-sec
- Preset window open & counts preset number of α-particles, measurable period of decay time
- Perform Hot and Cold reaction
- Analysis of decay chains; 34 decay chains measured.
- Repeating experiment facility
- Reanalysis of all decay chain system available to identify spuriously decay chains

Investigated Elements: More than one element/isotopes are synthesized at SHIP, few of them are :(1) Bohrium(107), first element synthesized in SHIP by the reaction $^{54}Cr + {}^{209}Bi \rightarrow {}^{263}107^*$. In-flight recoil separation and generic correlation of parent-daughter nuclei with five decay chains.
(2) ^{261} Bh (Isotope) (3) ^{264} Bh : Grand daughter product in the decay chain of ^{272} 111
(4) ^{66} Bh & ^{267} Bh by HFR ^{22} Ne + ^{249} Bk → ^{271} Bh*. Remember that nuclei were identified after chemical separation. (5) Hassium, ^{264} Hs , ^{269} Hs, ^{270} Hs , out of these three, ^{269} Hs as a link in the decay chain of ^{277} 112, and ^{270} Hs due to recent chemistry . (6) Meitnerium, ^{266} Mt and ^{268} Mt irradiation of ^{209}Bi with ^{58}Fe and later was neutron rich, measured after α-decay of ^{272} 111. Identification of neutron rich elements and using them as projectile, (^{64} Ni) as an art-of-reaction, may enhance cross-section. Enhancing neutron number by a particular number (odd/ even) not proven absolutely that ‘ the cross-section’ are increased. On going research at SHIP, will be extending the periodic table.

Investigated elements at SHIP was 112, reaction is ^{70} Zn + ^{108} Pb → ^{278} 112* by irradiation and calculated cross-section is 0.5μμb. Re-investigation based on need or repeating the experiment whenever there is a doubt in decay chains. During the re-investigation, time period remains constant but, the intensity of the beam slightly change (slightly higher) and measuring the decay pattern of the first. This is must, to find out spurious decays. In the year 1999, experiment at 88-inch cyclotron in Berkely and synthesized the element 118. and the same was repeated using Berkely Gas filled Separator(BGS) through reaction ^{86} Kr + ^{208} Pb → ^{293}118* was investigated, three decay chain, a surprising high cross-section of 2pb! for one neutron emission channel. Due to high cross-section value, it needed confirmation, done at SHIP, for the same measuring time: 24 days, and found that: collected projectiles are 2.9X10^{18} and 2.3X10^{18}, closely and verified that, there is no event chain (no decay chains). Hot and Cold fusion reaction does not depend on neither whether conditions nor the country where the experiment is performed.

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4.0 COLD & HOT FUSION REACTIONS (CFRs & HFRs)

4.1 COLD FUSION REACTIONS: A fusion is said to be a 'cold fusion reaction if it is:

- Low Energy Nuclear Reaction (Bubble fusion)
- Excitation energy of a compound nucleus is low, approximately 10-20MeV

(Barrier energy, even less in the center-of-mass system corresponds to the fusion barrier.

-Reaction of the type X + (Pb, Bi) → SHE+1n

-Cross-section in case of synthesis of SHEs is very small and decreases strongly with increasing atomic number.

4.2 Elements produced in CFRs:

Elements 107 to 112 based on lead and bismuth targets, produced Bohrium (Bh) 107, Hassium (Hs) 108, Meitnerium (Mt) 109 and Element 110, 111, 112. Out of these, most of the elements synthesized at SHIP using the method of in-flight recoil separation and generic correlation of parent-daughter nuclei. Reactions for the above elements (107-112) are as follows:

Element 107:

^{54} Cr +^{209} Bi → ^{263} 107* with 5 α-decay chains. Isotopes ^{266}Bh and ^{267}Bh were produced using the ' hot fusion' reaction ^{22} Ne + ^{249} Bk → ^{271} Bh* (nuclei identified after chemical separation).

Element 108:

^{58} Fe + ^{208} Pb → ^{266} 108* with one α-decay chain ^{264} Hs (even-even isotope) and ^{269} Hs (odd) identified in the link decay chain of ^{277} 112.

Element 109: ^{58} Fe + ^{209} Bi → ^{277} 109* With Single decay chain. The Neutron-rich isotope ^{268} Mt was measured after α-decay of ^{272} 111.

Element 110: ^{62} Ni + ^{208} Pb → ^{269} 110 + 1n

Heavier isotope ^{271} 110 was synthesized with a beam of the more neutron-rich isotope ^{64} Ni. Two more isotopes ^{267} 110 (at LBNL) and ^{273} 110 (at JINR) produced by the irradiation of ^{209} Bi with ^{59} Co and ^{252} Pu with ^{34} S respectively in which ^{59} Co and ^{34} S are taken as projectiles. Total eight α-decay chains were measured.

Element 111: ^{64} Ni + ^{209} Bi → ^{273} 111*, three α-decay chains of the isotopes ^{272}111 were observed.

Element 112: ^{70} Zn + ^{208} Pb → ^{278} 112*

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During investigation of the element 112, one α-decay chain was observed but again, at the time of verification, additional decay chain was also observed for the same duration of 24 days, but there is some slightly increase in energy beam. During reanalysis with respect to predetermined period of duration, the number of decay chains may vary. To observe residual nuclei: SHIP and BGS are most suited instruments with good detecting techniques.

5.0 HOT FUSION REACTIONS: A fusion is said to be a hot fusion if it is performed with

(1) Targets made with actinides
(2) Beam energy35-40MeVis required to initiate fusion reaction (actinides target)
(3) Beam energy 10-20MeV is required to initiate fusion reaction (Lead target)
(4) ≥ 3 to 5 neutrons are released
(5) n-rich isotopes are considered
(6) high cross-section

5.1Reaction (1):

$^{48}Ca + ^{242}Pu \rightarrow ^{290}114^{*}$, In this reaction, three α-decay chains were observed that produce the nuclide $^{287}114$ and would decay by α-emission into $^{283}112$. Over a period of 21 days, a total of four fission events were detected. Out of these, two from 112 and rest from 114 of the ^{238}U and ^{242}Pu. Search for element 114 at Flervo Laboratory of Nuclear Reaction, FLNR, and the Lawrence Livermore National |Laboratory , LLNL, Livermore, in which ^{244}Pu target was irradiated for a period of 34 days with a ^{48}Ca beam and from the data, only one decay chain was extracted, for the decay of $^{289}114$ with a cross-section 1pb. And $^{289}114$ or $^{288}114$ in the form of daughter product after evaporation of 3 or 4 neutrons and cross-section is about 0.6pb, recorded.

5.2Reaction (2):

$^{48}Ca + ^{242}Pu$ and $^{48}Ca + ^{244}Pu$, is measured for a period of 34 days and just within one year[1998-1999] difference , two more α-decay were recorded with sequences of spontaneous fission and observed that, these are identical with respect to statistical fluctuations and detector-energy resolution .

5.3Reaction (3):

$^{26}Mg + ^{248}Cm \rightarrow ^{274}Hs^{*}$, due to this reaction, five neutrons evaporation and isotope ^{269}Hs was produced. Volatile compound like HsO_4 formed, if decay reacted with Oxygen, by chemical means. For synthesis of long-lived nuclides, using HFRs for which cross-section vary from 10nb to few pb with beam intensities of 3×10^{12}ions /sec using target of thickness of about0.8mg/ cm^2. This is to get long-lived nuclides through HFR, that is useful in chemical studies and also to note that, during HFRs minimum 4 and maximum 5 neutrons evaporation was observed.

Conclusion:

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Error free experimental set up and experimental investigations for the production of SHEs is the main avenue, because increasingly difficult with increasing element number due to the decreasing fusion evaporation cross-section. So, standard experimental techniques and parameters such as beam energy/excitation energy for cold and hot fusion reaction for all SHEs under Heaviest system, wider range analysis required. Few are:

- Selection of Cyclotron, SHIP or any other instrument and coordinate system
- Decay chains and evaporation of number of neutrons and residue
- Excitation functions, rigid body moment of inertia, kinetic energy
- Vibrational and rotational collective motion
- Selection of model and quantum mechanical approximations etc
- Calculations of un-wanted errors or minimization
- Perfect differentiation between cold and hot fusion reaction

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Biography:

1. Mohammed Najmuddin Khan, Head Department of Physics, Govt Degree College (B^{+}), Deverakonda, Dist:Nalgonda, 508248, Under Mahatma Gandhi University, Nalgonda, Telangan State. Published two Research Papers (i) Superheavy Elements-its Annals, www.research-chronilcer.com , ISSN. (ii) www.jchps.com (Special issue) ISSN (iii) 2011-12 to 2014-15, regularly published full length research paper In National Conferences, organized by the Department of Chemistry, University of Calicut, Kerala. (iv) As resource per delivered a lecture in Mahatma Phulay A S C College, Panvel, Navy Mumbai. (v) As a resource Person attended a State Level Seminar, On Radiation Physics…….All certificates in hand, available. Contact: 09441 786 153
2. Dr Ranjeet A Mandal PhD, Sr Principal and Guide, Subash Chandra Bose Degree College, Mulchera, Gadchiroli Dist. Maharashtra State, India.