# Nuclei in the High Spin States Beams for Super Heavy Elements Production

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## Abstract

In the last three decades more than one hundred of new isotopes with $Z > 103$ have been discovered in cold fusion reactions with Heavy Ions, with the dream to reach the Super Heavy Nuclear Island. This Island was theoretical predicted in the seventies to be situated around $Z=114$ and $N=184$. The fusion cross sections in reactions with $^{48}$Ca on heavy targets are of the order of the pico barn, it means a few months of experiment for few events, in the normal experiments with the actual accelerators intensities and targets. New ideas can be proposed: collision between two heavy nuclei with high spin ground state or the combination of the heavy nuclei with high spin isomer. These high spins states can stabilise the double nuclear system and rise the chance to go into fusion. We suggest to use the advantage of High Spin Isomer States, by tacking into account the importance of the quantum number G (spin - isospin coupling) suggested by Ripka [1]. The $^{178}$Hf $^{2m}$ (2m means second isomer, $I=16\hbar$, 31years life time) is an interesting nucleus. In this article we propose to use this isomer as a target (projectile) for production of SHE. More, we suggest other high spin targets projectile combination like: $^{117}$Sn($I=11/2^-$, 14d) + $^{176}$Lu ($I=7^-$, 38Gy) $\rightarrow$ $^{293}$121 .

**Keywords:** Nuclear Fusion Reaction, Heavy Ions, Super Heavy Elements SHE, $^{178}$Hf$^{2m}$ high spin isomer isotope.

## 1. Introduction

The fusion reactions have been used for the last decades to make new heavy elements with $Z \geq 104$. Unfortunately experimental fusion cross sections are smaller and smaller down to $10^{-36}$cm$^2$, exponentially decrease, it means one real event in a few weeks. Secondly, neutron rich natural radioactive projectile or targets are missing on the market.

Three years ago, we proposed [2] to use the $^{178}$Hf$^{2m}$ isomer like miraculous battery to store up (save) and indicate how to extract this energy. In this article we suggest another use for this isomer as a target (projectile) for SHE production.

Having in mind the importance of spins of the projectile and targets in the fusion reactions [3] (the cross section grows with the nuclei spins) we suggest to use the high spin isomer of $^{178}$Hf$^{2m}$ ($I=16$, I is the total spin of the nucleus) like target and projectile or combinations of $^{178}$Hf$^{2m}$ and $^{180}$Hf. The problem of missing excess of neutron can be

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attenuated by the effect of the high spin of the nucleus I. This idea comes from the work of Ripka [1], where the spin of the nucleon and his isospin are treated together with the new quantum number G (the definitions will be done later). The angular momentum of the reaction l is not playing the same role in the fusion cross section. If the fusion is obtained (due to the high spin of isomeric state) the approach to the SHE island (Z=114, N=184) will be from the east part of island and we believe that the same kind of chains of alpha particles will decay on the north east side of SHE island. The decay of the complex nucleus obtained in this fusion reaction with an evaporation of one or a few neutrons can be through a chain of fifteen alphas and will reach the predicted more stable super heavy nucleus (Z=114, N=182).

Another example of combination of two nuclei with high spins of ground states are $^{117}$Sn and $^{176}$Lu with spins : $I=11/2^-$ and respectively $I=7^-$. The compound nucleus formed will have 121 protons and if we suppose an evaporation of one neutron, the five alpha decay chain will reach the already known isotope $_{111}{}^{272}$Rg.

## 2. Superheavy Elements Production

After the discovery of the shapes isomers by Polikanov [4] in Dubna 1962, Strutinsky [5] suggested in 1967 the Shell Model Corrections (SMC) approach to explain the double hump barriers in some fissioning nuclei. With this SMC the theoretical calculations find "new magic numbers" for SHE. It means, from end sixteenth, the nuclear scientists think that the center of the island of SHE is the nucleus with: Z=114 and N=184. New magic number Z=114 is well smaller than the old one Z=126 giving hopes to reach this island by hard experiments.

The first attempt to reach this island have been done in Dubna in 1973, where a special arrangement was realised to put two cyclotrons in tandem U300 and U200 and to accelerate $^{136}$Xe ions to collide $^{238}$U nuclei, at the energy higher (6.6MeV/A) than coulomb barrier, $B_c$ = 467 MeV in center of mass, and 734 MeV in laboratory frame. The fission cross section for this reaction, was reported to be of the order of $10^{-33}$cm$^2$, this value, being not confirmed four years later with the new Darmstadt linear accelerator [6] for the same reaction and bombarding energy of 7.6MeV/A. The Darmstadt scientists looked up to very small cross sections $10^{-35}$cm$^2$. Even seven year later, the experiment [7] do not confirm the SHE, even if theoretical calculations were done [19].

Two decades later, by using asymmetrical target projectile combinations, and an ideal projectile $^{48}$Ca (very expensive), many chains of few alpha particles decaying ground states of the SHE have been measured. Roughly, few dozens of the decaying alpha chain, of three or more alpha have been published with their energy $E_\alpha$ from 8 to 12 MeV and the decaying time $T_{1/2}$ , from microseconds to tens of hours. We count more then 100 new isotops synthesized for the elements with Z>101.

The following heavy elements have been already synthesized: Z = 102 to 116 and 118 at GSI, Darmstadt; isotopes of Z = 114 to 116 and 118 at JINR-FLNR, Dubna;

Recently Yuri Ts. Oganessian (future Nobel prize in Physique) synthesized 2 isotopes of Z = 117 at Dubna [8] and succeeded measurements for two alpha α chains decaying from this element. These data are not included in the fig. 1 which try to summarise the all SHE known today.

The α-decay half-life of most nuclei have been experimentally measured or theoretically predicted from a "mass formula" with estimated coefficients. $Q_\alpha$ are different for several authors, e.g. Koura-Uno-Tachibana[9] , Myers-Swiatecki[10] and Muntian-Patyk-Sbiczewski [11].

There are claims, Marinov et al. [12] for evidence for a long-lived superheavy nucleus with atomic mass number A = 292 and atomic number Z =122 in natural Th.

From the theoretical point of view the concepts of "SHE Island", "Island of Stability" and the "Magic Island", are related to the long live time obtained in the theoretical calculations for the alpha decay or fission [13]. The SHE stability result from the extra-binding which appear due the shell effect. In the seventeenth [14] the calculations reported the spherical doubly magic nucleus Z=114, N=184 (and an Island of Spherical SHE), based on the shell gap at Z = 114. This is due to the spin-orbit interaction. Later on, by using the deformed Nilsson orbitals have been obtained the deformed doubly magic nucleus Z=108, N=162 and modern theories predict Z=120, 124 and 126, N= 184, 172 also as magic numbers for spherical nuclei [15], [16].

To go further new projectiles rich in neutron are proposed (radioactive beams) and new heavy targets (radioactive targets) are proposed and thousands of millions of dollars are projected to build the special accelerators, reaction chambers, etc. And we are not sure to go to our goal.

## 3. Spin-Isospin Coupling for Superheavy Elements Production

The isospin quantum number was introduced by Heisenberg [17] in 1932, immediately after the discovery of the neutron by Chadwick [18]. The isospin t (like the spin s of a particle) has a matrix character (like Pauli matrix). The $t_z$ being the z projection of the isospin show the nature of the nucleon in the nucleus: for proton

$$t_z = -\tfrac{1}{2} \qquad (1)$$

and for neutron

$$t_z = \tfrac{1}{2} \qquad (2)$$

The total nucleus isospin is

$$T = (N - Z)/2 \qquad (3)$$

In the description of the nucleus the spin – orbit interaction (coupling) play a fundamental role which permit to explain the existence of magic numbers. These magic numbers are dependent also on the deformation parameter

Few years ago Ripka [1] suggested to associate the spin **j** and the isospin **t** of a nucleon , in a new quantum number of a nucleon, the big **G** :

$$\mathbf{G} = \mathbf{t} + \mathbf{j} \qquad (4)$$

(this notation means a vector). The total spin of the nucleus **I** is a complicated summation of the spin **j** of the nucleons. Ripka was able to calculate in the shell model type calculation the levels for the neutrons and protons which present different gaps (relative to usual shell model calculation) and may be different magic numbers, indicating the complex mixing of the isospin and spin and their similarities (correspondences). See the known isotopes of heavy and superheavy elements [1].

Having in mind the importance of spins of the projectile and targets in the fusion reactions [2] (the cross section grows with the spins) we suggest to use the high spin isomer of hafnium, like target and projectile or combinations of $^{178}Hf^{2m}$ ($I=16\hbar$) and $^{180}Hf$. The missing neutrons are replaced by the stabilizing effect of the high spin.

The angular momentum l (coming from the relative movement of the projectile and target) do not play a same role in the fusion reaction cross section. The high spin of the isomeric states brings a qualitatively different spin in a heavy ion fusion game.

Then, if the reaction energy is classically chosen to obtain a complex and to expect evaporating of few nucleons (neutrons) we will be able to reach nuclei with even higher Z. Usually, in the new era of SHE the detection and their identification is made through 4 - 10 alpha particle in a nuclear chain. So, in the case of Hf on Hf reaction, chains of 8 to 15 alphas will go closer to Z=114, N=184. We will explore the SHE island coming from the north east of the island. Through this kind of reaction we have the possibility to obtain tens of new isotops.

To realise this kind of reaction we have to overcome many technical problems. The target material does not exist and a special nuclear reaction should be performed to obtain an quantity $10^{18}$ nuclei. May be, by using $^{238}U$ beams fragmentation, like in Darmstadt in inverse kinematic we can obtain beams of $10^{8}$ nuclei of Hf isomer per second (with 5% purity).

Through the other possibilities we propose the reaction:

$$^{117}Sn + {}^{176}Lu \rightarrow {}^{293}121 \qquad (7)$$

where we take advantage of the high spins of the ground states of the both nuclei : I=11/2 for $^{117}Sn$ and I=7 for $^{176}Lu$.

If we calculate the

$$G_{exp} = T_z(Sn) + I\,(Sn) + T_z(Lu) + I\,(Lu) \qquad (8)$$

$$G_{exp} = (17/2 + 11/2\,) + (34/2 + 14/2\,) = 38 \qquad (9)$$

and supposing for tne nucleus $^{293}121$ the I = 0 than:

$$G_{th} = (51/2 + 0\,) = 25 \qquad (10)$$

Therefore $G_{exp} > G_{th}$. The weak number of neutrons in the compound nucleus $^{293}121$ is "compensated" by the spins (11/2 and 14/2 ) of the colliding nuclei. The spin

$$I_{total} = 11/2 + 14/2 \qquad (11)$$

brought in the collision play a stabilising role "like the twelve missing" neutrons (305-293=12).

The same calculation is possible for the Hf plus Hf reaction. The $I_{total}$ in the hafnium case is

$$I_{total} = 16 + 16 = 32 \qquad (12)$$

Within linear extrapolation the increase of the ratio N/Z for the "stable" nuclei, the compound nucleus with Z=144 will have N=238 and number of nucleons 382. This nucleus has 34 neutrons more than the supupposed stable 356 ( Hf plus Hf , 178 +178). In both cases the spin – isospin coupling suggested by Ripka [1] work very well.

## 4. Conclusion

The $^{178}$Hf$^{2m}$ is a challenge nucleus by itself. Nevertheless we have hopes to separate few millimoles of this atom and to do ultimate experiments to produce SHE. The theoretical work of Ripka [1] on the coupling between spin and isospin of the nucleons in the nucleus give us new hopes to reach the SHE (Z=114,N=184) through long chains of alpha decay (8 to 15) which will decay the complex nucleus formed in bombarding targets of $^{178}$Hf$^{2m}$ with $^{178}$Hf$^{2m}$ projectiles. We find another combination satisfying the big G rules, the spin of the nucleus and the isospin playing similar game. The case of $^{117}$Sn (I=11/2$^-$ , 14d) + $^{176}$Lu (I=7$^-$ , 38Gy) → $^{293}$121 is different in a sense that both nuclei are in the ground state. This hypothesis can be verified in the fusion reactions more easy to realise.

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