Systematic alpha decay study and predictions for new superheavy elements

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Introduction

The next magic numbers beyond the doubly magic nucleus ^{208}Pb is a long standing question in the nuclear structure physics. A number of theoretical efforts [1,2] have been made in the late 1960's for the existance of long lived superheavy nuclei also the next magic numbers predicted Z=114, 124, 164 for protons and N=184, 196, 236, 318 for neutrons. Various models on the basis of Strutinsky approaches have found Z=114 more stable, whereas Hartree-Fock calculation based models predict the highest stability at proton number Z=120, 124, 126. The nucleus with Z=120 protons and N=172 neutrons is predicted to be doubly magic nucleus. Very recently G. G. Adamian et al., pointed out Z= 120 the next magic number beyond ^{208}Pb nucleus on the basis of evaporation residue cross-sections.

During the last two decades evidences has been confirmed experimentally connected to superheavy elements. The advancement in the accelerator technology has opened the door to synthesizing the new superheavy elements. The Z=107-112 superheavy elements are synthesized successfully using the lead and bismuth targets in the cold fusion reactions. Elements Z=114 and 116 identified by hot fusion reactions[3]. The hot fusion reactions are based on heavy actinide targets from Th to Cf with very light C to S projectile.

These heaviest isotopes decay predominantly by groups of alpha particles (or alpha chains) as expected theoretically. The minimum excitation energy are obtained using the ^{48}Ca beam in the hot fusion reactions. A possibility of ^{50}Ca has shown a better beam in for the formation of superheavy nuclei by cold fusion, since ^{50}Ca is a radioactive nucleus[4].

Preformed Cluster Model

The preformed cluster model (PCM) [5] uses the dynamical collective coordinates of mass and charge asymmetries η and η_z on the basis of Quantum Mechanical Fragmentation Theory. The decay constant λ in PCM is defined as

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P \tag{1}$$

Here P_0 is the cluster preformation probability and P is the barrier penetrability which refer, respectively, to the η- and R- motions. ν_0 is the barrier assault frequency. P_0 are the solutions of the stationary Schrodinger equation in η,

$$\left\{-\frac{^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta)\right\}\psi^{(\nu)}(\eta)=E^{(\nu)}\psi^{(\nu)}(\eta) \tag{2}$$

Which on proper normalization are given as

$$P_0 = \sqrt{B_{\eta\eta}}\left|\psi^{(0)}(\eta(A_i))\right|^2 \left(2/A\right) \tag{3}$$

The fragmentation potential ($V_R(\eta)$ in eq (2) is calculated simply as the sum of Coulomb interaction, the nuclear proximity potential and the ground state binding energies of two nuclei:

$$V(R_a,\eta) = -\sum_{i=1}^{2} B(A_i,Z_i) + \frac{Z_1 Z_2 e^2}{R_a} + V_P \tag{4}$$

With B's taken from the 2003 experimental compilation of Audi et al and from the 1995 calculations of Moller et al. Thus, full shell effects are contained in our calculations that come from the experimental and/or calculated binding energies.

The WKB tunneling probability calculated is P= $P_i P_b$ with

$$P_i = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_i}\{2\mu[V(R)-V(R_i)]\}^{1/2} dR\right]$$

$$P_b = \exp\left[-\frac{2}{\hbar}\int_{R_i}^{R_b}\{2\mu[V(R)-Q]\}^{1/2} dR\right]$$

These integrals are solved analytically for R_b, the second turning point, defined by $V(R_b)$=Q-value for the ground- state decay.

The assault frequency ν_0 is given siply as

$$\nu_0 = \left(\frac{2E_2}{\mu}\right)^{1/2} \Big/ R_0 \qquad (7)$$

With $E_2=(A_1/A)Q$, the kinetic energy of lighter fragment, for the Q- value shared between the two products as inverse of their masses.

Calculation and Results

Table 1 shows the results of our calculation for alpha-decay half-lives. The results are compared with the calculation of GLDM , DDM3Y and with Expt. data .

Parents	PCM Log $T_{1/2}$(s)	GLDM Log $T_{1/2}$(s)	DDM3Y Log $T_{1/2}$(s)	Expt. Log $T_{1/2}$(s)
^{294}118	6.446	-5.60	-4.66	-2.745
^{293}116	5.63	-3.19	-1.883	-2.276
^{292}116	-0.12	-2.85	-1.97	-1.744
^{291}116	0.551	-3.57	-2.28	-2.201
^{290}116	-1.31	-3.58	-2.69	-1.823
^{288}115	0.271	-1.32	0.35	-1.06
^{287}115	2.353	-1.68	-0.598	-1.495
^{289}114	2.871	2.16	3.292	0.414
^{288}114	1.473	1.16	1.90	-0.097
^{287}114	1.496	0.74	1.905	-0.318
^{286}114	-0.51	0.51	1.262	-0.886

The second part of the calculation is based on the prediction of some superheavy nuclei on the basis of PCM model. Long half-lives or stability of superheavy nuclei being considered due to the shell closure effects either they are proton number or neutrons. Here we have calculated not only the half –lives of SHE (Z=120 isotopes) but also their decay characteristics i.e., Q-values, preformation probabilies and penetration probabilities. It is clearly shown from the table 2, that a small change in Q-value makes a significant difference in the half-lives. Also the preformation probability for $^{309-311}$120 nuclei is small as compared to other isotopes. Preformation probaility of ^{294}120 is larger as compared to others .

Table2: The calculated α-decay half-lives and other characteristics for ground state decays of superheavy nuclei, based on PCM. Binding energies are taken from the Audi-Wapstra and Moller et al., data table.

Parents	Q(MeV)	- Log P_0	-Log P	Log $T_{1/2}$(s)
^{289}120	13.886	5.524	11.138	-5.016
^{291}120	13.916	5.762	11.084	-4.832
^{293}120	13.685	5.903	11.053	-4.717
^{294}120	13.296	5.317	11.484	-4.866
^{295}120	13.356	6.52	11.399	-3.748
^{296}120	13.686	5.656	11.013	-5.003
^{297}120	13.536	6.521	11.390	-3.757
^{298}120	13.356	5.996	11.358	-4.312
^{299}120	13.107	7.252	11.648	-2.761
^{300}120	13.396	6.562	11.284	-3.819
^{301}120	13.666	7.227	11.199	-3.243
^{302}120	13.716	7.334	10.897	-3.439
^{303}120	13.846	7.818	10.989	-2.864
^{304}120	13.826	8.471	10.751	-2.447
^{305}120	14.476	8.728	10.397	-2.554
^{309}120	13.726	13.233	11.017	2.584
^{311}120	13.106	15.886	11.669	5.900

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