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Affirmation of neutron Magicity in Livermorium isotopes of super heavy elements

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Abstract

The discovery of new super heavy elements and its stability is an on-going research work in the field of nuclear physics. Various models have been used to identify and investigate the properties of super heavy elements. Alpha decay is an important tool to identify and study the properties of super heavy elements (SHEs). The study of α-decay has been used for identifying the shell closure effects including the sub shell closures by calculating the decay half-lives. In the present work, our aim is to study the alpha decay half-life time of the super heavy nuclei- Livermorium (Lv, Z=116) without deformation by using Cubic plus Yukawa plus Exponential (CYE) model by two sphere approximation. [1, 2] The half-lives for alpha decay computed using this CYE model is compared with the theoretical predictions of Moller *et al*. From the results obtained we foretell about the feasibility of neutron shell closure which enhances the stability of the Livermorium nucleus and its daughter Flerovium (Z=114) nucleus.

Keywords: alpha decay, half-life time, shell closure, trans-actinides, super heavy nuclei

1. Introduction

Now-a-days, the study of super heavy nuclei is an interesting topic in the nuclear physics field. As per Seaborg, the stability determination is one of the thrust area in current nuclear physics. As per liquid drop model, no nuclei were stable for Z≥100, because of large coulomb repulsion. Neutrons, being neutral and can be polarizable, tends to occupy possibly an outer shell when the nuclei are heavy in the Lanthanide and Actinide series. Therefore this outer shell filled nucleons or magic nucleons present in the nuclei enhances the stability of the nucleus. Super heavy isotopes with magic numbers of nucleons are said to exist in an "Island of stability". Except the magic nucleons 2, 8, 20, ---- 126, which are comprehended in spherical nuclei, many theoretical calculations predict that super heavy nuclei can have other magic nucleons as by their theoretical models and computations. The stability of super heavy nuclei against the coulomb repulsive force is also because of one of the factor called shell closure. The neutron to proton ratio N/Z is in the range 1.433 – 1.614 and this increase with mass number neutralizes the coulomb repulsion. The stability of 'SHE' via alpha decay is discussed in this work.

2. Cubic plus Yukawa plus Exponential (CYE) Model

In this work, in order to study the decay properties we have used a realistic model [3], called as CYE model in which we use a cubic potential in the pre-scission region connected by Coulomb plus Yukawa plus Exponential potential in the post scission region. Here the zero-point vibration energy is explicitly included without violating the conservation of energy. The alpha particle pre-exists within the nucleus at a certain distance from the nucleus and the potential encountered by this alpha particle is purely coulomb. This potential as a function of r which is the center of mass distance of the two fragments for the post scission region is given by

$$V(r) = \frac{Z_1 Z_2 e^2}{r} + V_n(r) - Q, r \geq r_t \quad (1)$$

For calculating the zero – point vibration energy E_v,

$$E_v = \frac{\pi\hbar}{2} \frac{\left[\frac{(2Q)}{\mu}\right]^{1/2}}{(C_1 + C_2)} \quad s$$

Where C_1 and C_2 are the central radii of the fragments and given by

$$C_i = 1.18\, A_i^{1/3} - 0.48; \; (i=1, 2)$$

and

$$\mu = \frac{mA_1A_2}{A}$$

Where μ is the reduced mass of the system and m is the mass of the nucleon
Half-life time value of the alpha emission is calculated using the formula

$$T = \frac{1.433x10^{-21}(1+exp\ k)}{E_v} \quad (2)$$

3. Alpha decay half life time computation

Majority of super heavy elements are identified through the alpha decay chain [4]. In this work, we have calculated the alpha decay half-lives without deformation [5, 6] for Livermorium isotopes. In Table1, the computed half-lives using CYE model are compared with the theoretical predictions of Moller *et al* [7]. Fig.1 & 2 shows the comparison plot between calculated half life time values using CYE model and with reference values. The plot follows the same trend as the referred data and it agrees well.

4. Neutron Magicity of Livermorium Isotopes

Microscopic-Macroscopic (MM) theory predicts that there is an enhancement in stability when the shell closure exits at Z = 114 and N =184" [8]. "Both non-relativistic (Skyrme-Hartree, Fock-Bogliubov) theory [9] and Relativistic microscopic mean field theory (RMF) predicts that probable closures occur at Z = 114,120. RMF also predicts that additional shell closures exists around $Z \sim 108$ - 110; $N \sim 162$ and $N \sim 172$, along with N = 184 and Z = 114 [10, 11, 12]. Other than recognized magic numbers 2,8,20,28,50,82 & 126, the sequence of magic numbers extends to 114,124,164 for protons and to 184,196,236,318 for neutrons [13, 14, 15].

In the present work, alpha decay half-life time values are computed using CYE model and from the half life time values the presence of shell closures are identified. At shell closures the value of decay energy decreases and half life time value increases which makes the nuclei stable. The lower value of decay half –life time indicates the presence of shell closure in the daughter nucleus where as a comparatively higher value of half-life time predicts the same about the parent nucleus.

Using our data, curve is plotted for Q (MeV) versus Neutron number of daughter nucleus and recorded in Fig. 3. Similarly the curve for half life time value versus Neutron number of the daughter is plotted in Fig. 4. These two figures are found to be the mirror reflections of each other. Both these predict that these mirror reflections are due to the presence of shell closure at N = 162 & 196. The lower value of the half-life indicates the presence of shell stabilized daughter nucleus with N_d=162, where as a comparatively high value of half-life tells the same about the parent nucleus with N_d=196. As per our model the predicted new magic neutron number N=162 at which shell closure appears coincides with the experimentally verified process of decay of the nuclide ^{277}112 measured at Gesellschaftfür Schwer ionenforschung (GSI), Darmstadt, Germany [16]. Also our prediction agrees with the theoretical Relativistic mean field (RMF) theory [9]. The prediction for the existence of next new magic number N =196 as per CYE model is also confirmed by the physicist J.V. Kratz [17, 18].

Table 1: Comparison of Half-life time values calculated using CYE model with the reference values for Livermorium isotopes of SHE.

A_p	N_d	Q (MeV)	$\log T_{1/2}$ (s)	
			CYE Model	Reference values[7]
280	162	12.42	-4.46	-5.10
282	164	11.66	2.76	-3.43
284	166	11.60	-2.66	-3.28
286	168	11.42	-2.25	-2.85
288	170	11.32	-2.04	-2.61
290	172	11.12	-1.57	-2.12
292	174	10.82	-0.81	-1.37
294	176	10.97	-0.181	-1.75
296	178	11.10	-1.62	-2.08
298	180	11.22	-1.96	2.37
300	182	11.41	-2.47	-2.82
302	184	11.95	-3.79	-4.06
304	186	11.91	-3.73	-3.99
306	188	11.45	-2.66	-2.93
308	190	11.01	-1.58	-1.84
310	192	10.41	0.03	-0.26
312	194	7.80	9.23	8.58
314	196	6.11	18.17	17.19
316	198	7.54	10.34	9.74
318	200	7.44	10.78	10.18
320	202	7.71	9.50	8.99

A_p denotes mass number of parent nucleus

N_d denotes Neutron number of daughter nucleus

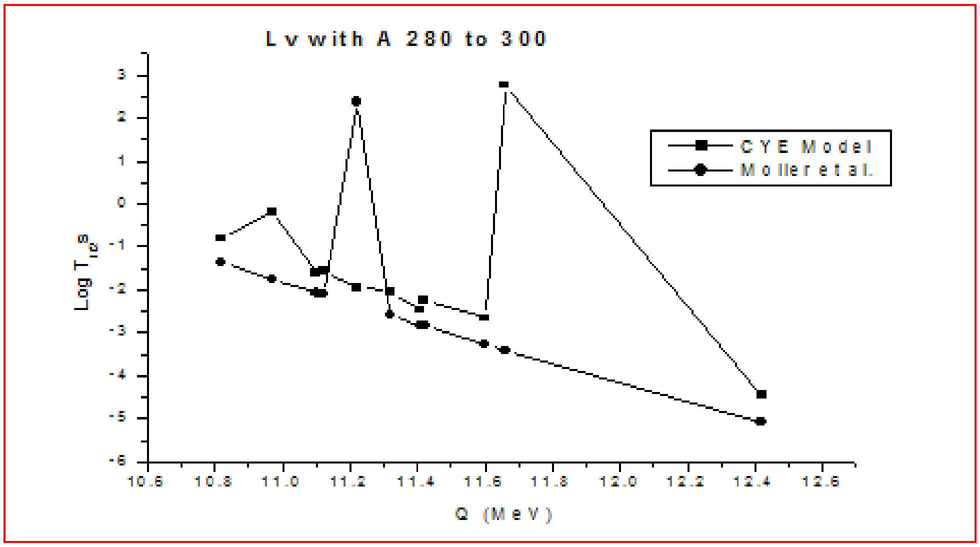

Fig 1: shows the comparison plot between calculated 〖log〗⁡〖T (1⁄2) (s) using CYE model and reference values for the isotopes of Lv with A = 280-300.

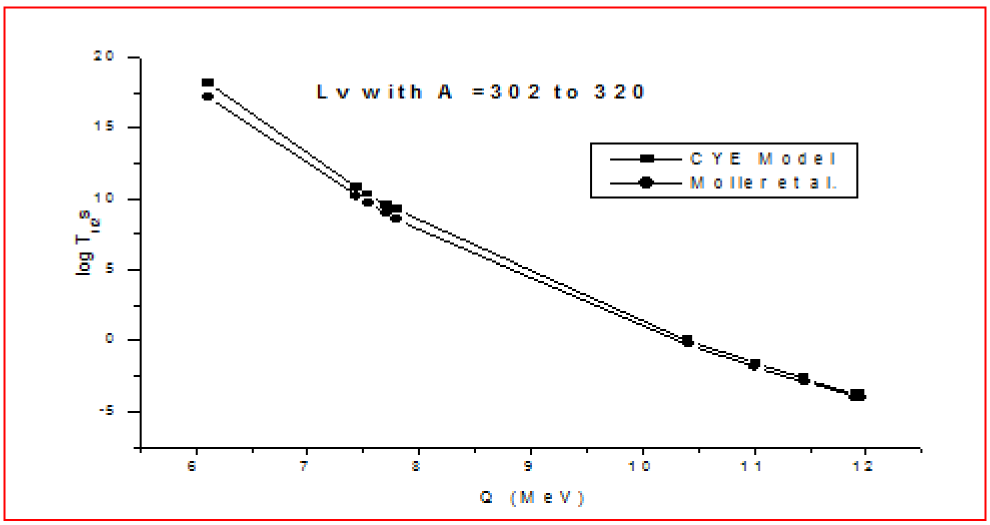

Fig 2: shows the comparison plot between calculated 〖log〗⁡〖T_ (1⁄2) (s) using CYE model 〗 and reference values for the isotopes of Lv with A = 302-320.

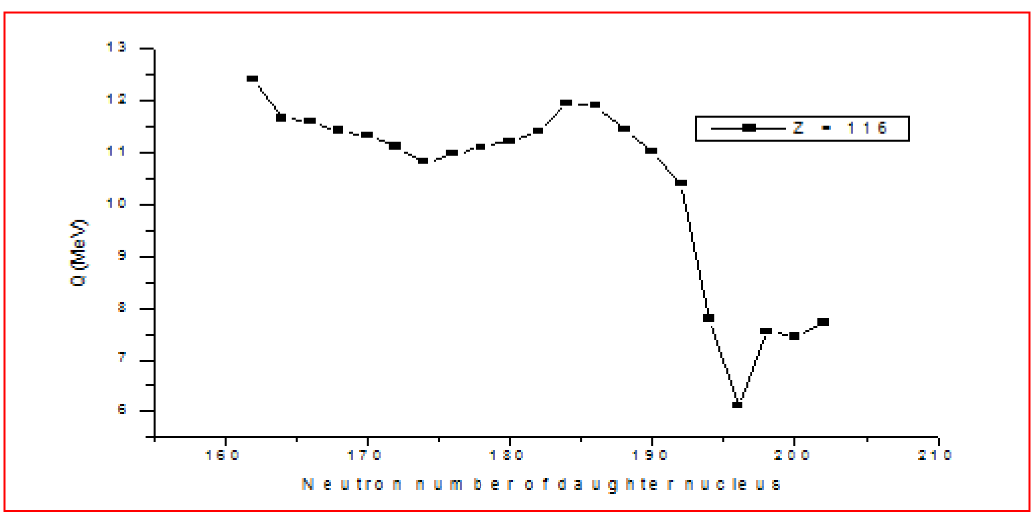

Fig 3: represents the plot of Q-value (MeV) vs. Neutron number of daughter nuclei of Livermorium nucleus.

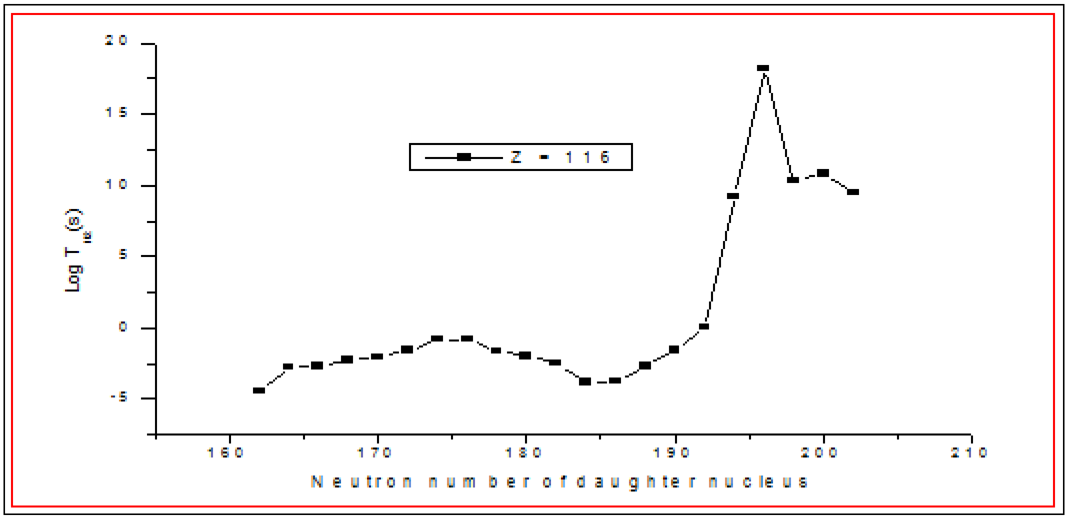

Fig.4 represents the plot of half-life time vs. Neutron number of daughter nuclei of Livermorium nucleus.

5. Results and Discussion

Using CYE model the half-life time values are calculated for alpha decay from Livermorium nuclei without including deformation effects. The computed results are compared with the theoretical values. A small value of decay half -life time values indicates the presence of shell closure in the daughter nucleus. The decay studies shows that half-lives of the alpha decay work as a tool in nuclear structure physics to study the presence of shell effects of the parents as well as of daughter nuclei. Among many empirical evidences that explain about the existence of magic neutron numbers, our premise CYE model pin points the appearance of nuclear magicity of Livermorium isotopes with neutron numbers N=162 & 196. Thus our interpretations lay a concrete path for future predictions for the existence and stability enhancement of super heavy elements due to the presence of magic nucleons.

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