Alpha decay Q-value of Superheavy nuclei

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Introduction

The prediction of the existence of superheavy nucleus (SHN) in 1960s, created an enthusiasm in synthesis and identification of SHN, worldwide. A number of theories have been applied to predict the most stable nucleus in the superheavy region. But the location of the closed shell in the island of stability is still uncertain. Beyond the closed spherical shells at Z=82 & N=126, deformed shell closures at Z=108 & N=162 has been identified[1], but the next spherical shell closure is still open and different theoretical approaches predicted different spherical shell closures, depending on the model employed. While the macro-micro models favour Z=114 & N=184, the relativistic mean-field approaches generally prefer Z=120 & N=172 and self consistent Skyrme Hatree-Fock calculations focus at Z=126 & N=184. From the results obtained in recent years it is expected that there is a resemblance of lighter region of the nuclear chart in the upper right end corner.

Besides shell effects in the stability of SHN, the α-decay or spontaneous fission(SF) took important role. SHN with atomic number beyond 110 predominantly undergo sequential α-decay terminated by SF. In experiment, the measurement is mainly α-decay Q-values and half-lives, while the major goal of the theory is to predict the half-lives to serve the experimental design. Q-value, one of the crucial quantity for a quantitative prediction of decay half-life, affects strongly the calculation of the half-life due to the exponential law, i.e., α-decay rates exhibit an exponential dependence (Geigger – Nuttall) on emission energy. Therefore it is extremely important and necessary to obtain an accurate theoretical Q-value for a reliable half-life prediction. In fact, it is a challenge to interpret the existing decay data in literature, with theoretical models in order to better understanding the complex nuclear structure phenomena and reaction mechanism. For the study of SHN, mostly, macroscopic-microscopic approach is used[2] and some mass formulae were proposed that combine the liquid-drop ideology with the shell-model corrections of Strutinsky or Mayers-Swiatecki[3] and some empirical formulae. In order to improve the agreement with experiment, different corrections were introduced in the mass formula by different authors, but it is claimed that the original simple physical sense will be lost and question its adequacy to the fulfillment of the requirements of experiment.

In recent experiments, α decay has been indispensable for the identification of new nuclides. During the experimental design the values of the α-decay half-lives have to be evaluated and hence it is quite important and necessary to investigate the α decay of SHN theoretically. Although α-decay is very useful for the study of the nuclei, a quantitative description of them with a satisfying accuracy is difficult. Initially the α decay was interpreted as a consequence of quantum penetration of α-particle. At present, many theoretical approaches have been being used to describe the α-decay in fission theories. The half-life is extremely sensitive to the α-decay Q-value and an uncertainty of 1 MeV in Q-value corresponds to an uncertainty of α-decay half-life ranging from 10^3 to 10^5 times in the heavy element region [4].

In this work we carry out the Q-value calculations with a correction factor in the mass formula to coincide with the experimental Q-values, and hence the half-life is calculated for the nuclide in the SHN region.

Mass formula and Q-value

Alpha decay is one of the most important properties of atomic nuclei, which is a powerful tool for the study of nuclei at the limit of stability (drip line), the closed shell nuclei and of heavy and superheavy nuclei. For the SHN, the α decay plays a key role since it determines the limit of their existence and allows to identify new elements.

The mass of the nuclei is calculated by computing the existing binding energy formula, $\Delta W(A,Z)= \alpha A- \beta A^{2/3} - \gamma Z^2/A^{1/3} - \xi((A/2)-Z)^2/A + \delta A^{-3/4}$, with the parameters, α=15.75MeV, β=17.8MeV, γ=0.71MeV, ξ=94.8MeV and $|\delta|$=34MeV, and hence the mass, $M(A,Z) = Zm_p + (A-Z)m_n - \Delta W(A,Z)$, where m_p and m_n are the proton and neutron masses respectively.

The α-particle energy,

$$E_\alpha = [M(A,Z) – M(A-4, Z-2)-M(^4He)]c^2.$$

In order for α-decay to occur, energy must be conserved, such that Q-values for α-decay can be determined [5]

$$Q_\alpha = A\, E_\alpha/(A-4) + [6.53(Z-2)^{7/5} – 8(Z-2)^{2/5}]10^{-5.}$$

Result

The discrepancy appeared between the calculated Q_α values with the $Q_{\alpha exp}$ [Fig.1], is reduced by adding a correction term, (–*ln*2) with the formula, and hence

$$Q_\alpha = A\, E_\alpha/(A-4) + [6.53(Z-2)^{7/5} – 8(Z-2)^{2/5}]10^{-5} – \ln 2.$$

Figure-2 shows the close agreement of the corrected Q-value with experimental Q_α of experimentally discovered/synthesized SHN. And hence the calculation is extended further to 290 nuclides in the SHN region (e-e, e-o, o-e, o-o) with $110 \leq Z \leq 128$, and the Q_α are plotted against Z, which is shown in fig.3.

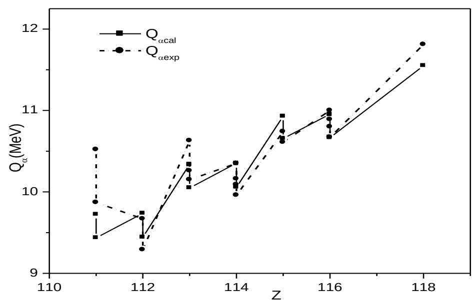

Fig. 1 Q_α modified and Experimental Q_α

The Q-value of the α-decay for odd Z nuclei are higher than even Z up to Z=120 and vice versa for Z >120, i.e., a major shift in the Q-value is observed, which is greatly influenced by shell effects. This may indicate the signature of sub-shell closure at Z=120, similar to the relativistic mean field prediction of next spherical shell closure[6]. Thus the existence of a shell effect (shell closure) is predicted at Z=120. Then, the obtained decay energies are used for the calculation of the decay half-lives using Viola-Seaborg formula[7].

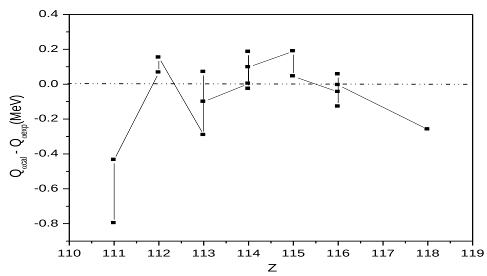

Fig. 2 Difference in Q_α-modified and $Q_{\alpha expt}$

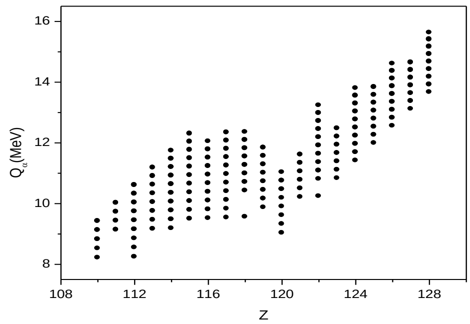

Fig. 3 Predicted Q_α for SHN, $110 \leq Z \leq 128$.

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