Spontaneous fission Vs Alpha decay of superheavy nuclei with reduced uncertainty of Q_α

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Introduction

In recent experiments, α-decay has been indispensable for the identification of new nuclides. Because the experimentalists have to evaluate the values of the α-decay half-lives, during the experimental design, it is quite important and necessary to investigate the α decay of SHN theoretically. Besides the role of 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 and long α-decay chains usually terminate by the 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 in a reliable half-life prediction during the experimental design.

For the study of SHN mostly macroscopic-microscopic approach is used[1] and some proposed mass formulae combine the liquid-drop ideology with the shell-model corrections of Strutinsky or Mayers-Swiatecki[2]. 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 has been lost and questioned its adequacy to the fulfillment of the requirements of experiment.

Alpha decay and spontaneous fission

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. We have already reported the Q-value with a correction factor in the mass formula as $Q_\alpha^{mod} = AE_\alpha/(A\text{-}4) + [6.53(Z\text{-}2)^{7/5} - 8(Z\text{-}2)^{2/5}]10^{-5} - \mathit{ln}2$, to coincide with the experimental Q- values, and hence the half-life was calculated for SHN [3]. For the superheavy region, the α-decay plays a key role since it determines the limit of their existence and allows to identify new elements. The experimental half life, $\log_{10}T_\alpha^{exp}$ vs $Z_d^{\ 0.6}.\ (Q_\alpha^{\ exp})^{-1/2}$, plotted by Silisteanu et al[4] obtained a universal straight line. Here the Q_α^{exp} is calculated using the measured kinetic energy of α-particle. It is to be noted here that in the calculation of T_α almost all the theories use either the extrapolated values of Audi et al.,[5] or the measured kinetic energy to calculate the experimental Q_α^{exp}. Using Q_α^{mod} [3] a higher value of slope and minimum error (rms=0.0007) was obtained[6].

The competition between α-decay and SF of superheavy nuclei were analysed recently by Kiren et.al.,[7].The phenomenological formula proposed by Ren and Xu [8], $\mathrm{Log}_{10}T_{1/2} = 21.08 + C_1(Z\text{-}90\text{-}\nu)/A + C_2(Z\text{-}90\text{-}\nu)^2/A + C_3(Z\text{-}90\text{-}\nu)^3/A + C_4(Z\text{-}90\text{-}\nu)(IA\text{-}52)^2/A$, and the parameters thereof are used in this work for the calculation of half-life period of spontaneous fission. ν is the seniority term introduced by taking the blocking effect of unpaired nucleon on the transfer of many nucleon-pairs during the fission process, and for SF of even-even nuclei, ν=0.

Result and Discussion

In this preliminary work we have calculated the T_α and SF half-lives using our modified

Q_α^{mod} [3]and the phenomenological formula[8], respectively. The ratio of spontaneous fission to alpha decay half-lives against relative neutron excess I=(N-Z)/A of even-even nuclei of Z=120-130 is plotted in figure.1. The range of mass taken for the calculation is, $^{284\text{-}300}120$, $^{288\text{-}304}122$, $^{292\text{-}312}124$, $^{294\text{-}316}126$, $^{296\text{-}320}128$, $^{298\text{-}326}130$. A convergence and divergence structure was obtained for the said range of Z and the convergence point which determines the dominant decay mode such as the nuclei located in the converging plot are possible alpha emitters and the nuclei located in the divergence section are spontaneous fission as their preferable decay mode. Hence most of the nuclei studied in this work are alpha emitters and they will survive against fission. It is to be noted here that the converging point obtained by Kiren et al.[7] using Q_α^{exp} is at relative neutron excess I = 0.20, and our result using Q_α^{mod}[3] also shows it at I=0.20, which confirms the reduced uncertainty in the prediction of Q_α.

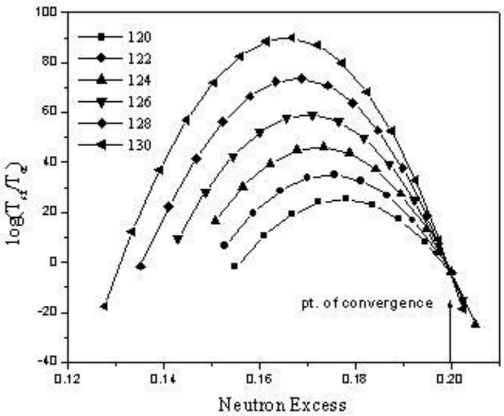

Fig. 1 The ratio of spontaneous fission to alpha decay half-lives against relative neutron excess of even-even superheavy nuclei.

For this possible α-emitter nuclei, the half-life period using Q_α^{mod} is plotted in Fig.2. The decay cahin of each Z nuclei gives almost a straight line within the range of N=164-196. From the Fig.2, the decay rate can be extracted since the Geiger- Nuttall law is a relation between the logarithm of the rate of alpha particle emission as a function of the alpha particle kinetic energy E_α. The results obtained is in agreement with the empirical result of Geiger-Nuttall Law. It is evidenced that several different groups of alpha particles with different energy are emitted by the same parent nuclei. A negative $\log_{10}T_\alpha$ value is obtained for the superheavy nuclei studied, and which explicitly shows its low life time.

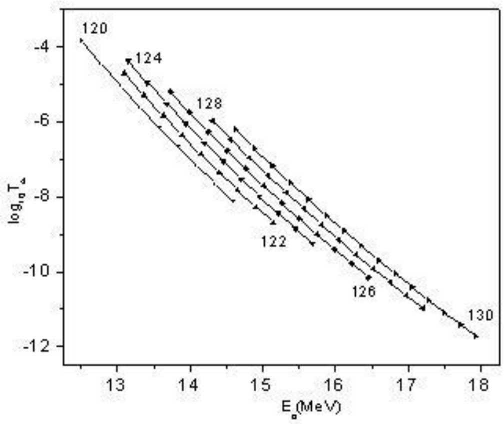

Fig. 2 Semi-log plot of the transition rate for alpha decay as a function of E_α, the kinetic energy of alpha particle. The calculated values for different isotopes of each elements, labeled by proton number Z are closer to straight lines.

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