Universal Gamow line for even-even superheavy nuclei

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Introduction

The extension of the periodic system into the islands of stability of superheavy elements is one of the main problems of modern nuclear physics. For the synthesis of these nuclei fusion-evaporation reactions are used either through cold or hot fusion reactions. The identification of SHEs in cold fusion reactions is based on the identification of the products via alpha correlations with known alpha emitters at the end of the decay sequences, but in hot fusion reactions the nuclei at the end of the decay sequences are neutron rich isotopes. Thus in this type of reactions an alpha-decay systematic based on theoretical calculations is necessary for the identification of the reaction products. The binding energies and/or α-decay energies also play important roles in identifying the newly synthesized nuclei. It is because α-decay is found to be one of the main decay modes in the superheavy region. Therefore, to calculate reliably the binding energies and the α-decay half-lives is useful for experiments.

The α-decay was firstly interpreted as a consequence of quantum penetration of α-particle by Gamow in 1928[1]. The earliest law for the systematics of α- decay lifetimes was formulated by Geiger and Nuttall[2]. This was the observation that $\log_{10}T_{1/2}$(sec) plotted vs $1/\sqrt{Q_\alpha}$, where Q_α is the α-decay Q value, empirically formed straight lines for a series of nuclei with the same charge number. 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 103 to 105 times in the heavy element region [3].

Formalism

Gamow[1] and independently Gurney and Condon [4] have solved the one body problem of the α-decay and derived the known Geiger-Nuttall relation from first principles of quantum mechanics. An explicit functional dependence of the halftime on the energy Q_α and Z_d was introduced later in formulations of Viola-Seaborg and Brown [5,6].

The Viola-Seaborg formula [5] is,

$$\log_{10}T_\alpha(\mathrm{sec}) = (aZ_d+b)Q\alpha^{-1/2} +(cZ_d+d)$$

where Q_α is the decay energy in MeV units, Z_d is the charge number of daughter nucleus. The parameters; a = 1.66175; b = -8.5166; c = -0.20228; d = -33.9069.

The Brown formula [6] is given as

$$\log_{10}T_\alpha(\mathrm{sec}) = 9.54\ Z_d^{(0.6)}\ Q_\alpha^{-1/2} - 51.37$$

The effective decay energy, $Q_\alpha = (A/(A-4))\ E_\alpha^{\mathrm{exp}} + 6.53 \ .\ 10^{-5}\ .\ Z_d^{7/5} - 8.0\ .\ 10^{-5}.\ Z_d^{2/5}$

The Brown formula was tested for 119 data points (T_α, Q_α) (in a range of Z_d from 74 to 106), and all these points falling on nearly universal line and stated that which represents the best linear fit to data [6]. In these formulations the α-decay probability is roughly the product of the probability of particle formation and the probability of barrier penetration. The first probability is considered the same from one nucleus to another, while the second one depends only on the Coulomb term of the potential, the nuclear term being neglected [6].

The earliest systematics of α-decay lifetimes of naturally emitters from actinides region was obtained [2] by plotting the experimental values of $\log_{10}T_\alpha$ vs $Q_\alpha^{-1/2}$ and the data for a given Z_d value fall on roughly a straight line and there is a large scatter between the lines for different Z_d values. To reduce the separation between the lines Z_d is incorporated with the Q_α and hence the plot for $\log_{10}T_\alpha$ vs $Z_d{}^{x}Q_\alpha^{-1/2}$, became a better plot for half-lives since, the lines for different Z_d values have a common slope. The value for x=0.5, 0.6 and 0.7 were tested and x=0.6 gave a better fit, since it minimizes the root mean square value. Brown[6] has plotted for 119 data points for a range of Z_d

from 74 to 106 and found that $\log_{10}T_\alpha$ vs $Z_d^{\,0.6}Q_\alpha^{-1/2}$ is the better way to plot the data.

Results and Discussion

The experimental half life $\log_{10}T_\alpha^{exp}$ vs $Z_d^{0.6}.\,(Q_\alpha^{exp})^{-1/2}$ was plotted by Silisteanu et al [7] and the universal straight line obtained was,

$$\log_{10}T_\alpha^{exp} = 9.6205\ (Z_d^{0.6}Q_\alpha^{-1/2}) - 51.0626 \quad (\text{rms}=0.5515).$$

Here the Q_α^{exp} is calculated using the measured kinetic energy of α-particle.

Silisteanu et al [7] plotted for 90 data points from Zd=100 to 118 with a rms =0.1257. When they plotted $\log_{10}T_\alpha^{th}$ vs. $Z_d^{0.6}.(Q_\alpha^{th}$-1/2 for Z_d from 102-120 the universal straight line is

$$\log_{10}T_\alpha^{th} = 9.6533\ (Z_d^{0.6}Q_\alpha^{-1/2}) - 52.2369 \quad (\text{rms}=0.4187)$$

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.,[8] or the measured kinetic energy to calculate the experimental Q_α^{exp}. An uncertainty of 1 MeV in Q value corresponds to an uncertainty of >100 times of α-decay half-life in the heavy element region. Hence we proposed a corrected formula for Q_α [9] with a correction factor of ln2 to suit to the superheavy region and obtained a very close agreement with the Q values of the experimentally found superheavy nuclei. Also the Q value for the higher Z superheavy nuclei are predicted[9].

In this work the half life period of even-even alpha emitters of 75 data points in the superheavy region Z_d ranging from 114 to 130 is calculated and the universal Gamow line is drawn for Viola-Seaborg formula[5] and Brown formula[6].(Fig.1 & 2). The slope and the rms values are analysed with the experimental data fittings and we obtained a higher value of slope and minimum rms for Viola-Seaborg formula and a very close agreement with the experimental fit (slope) and also obtained a very minimum error (rms) value for Brown formula, such as

$$\log_{10}T_\alpha(\text{VS}) = 10.70482\ (Z_d^{0.6}Q_\alpha^{-1/2}) - 57.7163 \quad (\text{rms}=0.2252)$$

$$\log_{10}T_\alpha\ (\text{Bn}) = 9.54004\ (Z_d^{0.6}Q_\alpha^{-1/2}) - 51.3702 \quad (\text{rms}=0.0007)$$

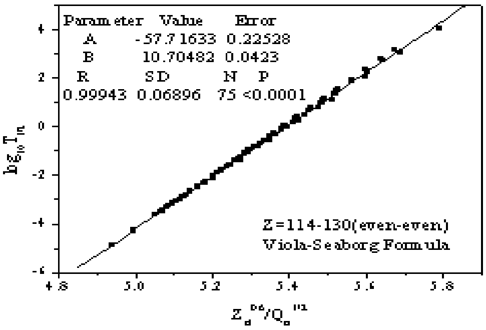

Fig. 1 The st. line represents the best fit of $\text{Log}_{10}T_\alpha^{th}$ values for the even-even SHN using Viola-Seaborg formula.

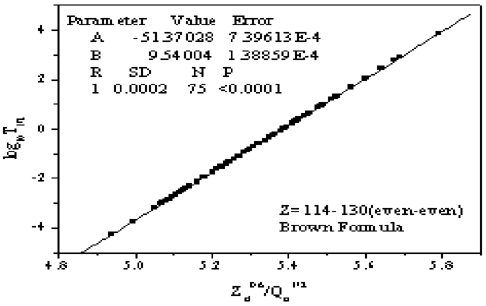

Fig. 2 Same as Fig.1, but for Brown Formula.

Hence it is strongly suggested that for even-even superheavy nuclei in the region >114 (yet to explore experimentally) the Brown Formula fit with our modified Q_α value is the best fit. And hence this systematic can be useful for detailed studies of new alpha emitters in the superheavy region.

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