

Viola-Seaborg Coefficients for Partial Alpha Half-lives Based on Latest NNDC Data

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Introduction

The Geiger-Nuttall law is an empirical relationship that describes the behavior of alpha particle emission rates for heavy atomic nuclei. It reveals a straight line with a slope of A_Z and an intercept of B_Z when plotting the logarithmic graph of α half-life of given isotopes vs. the inverse square root of effective α energy. Viola-Seaborg (VS) coefficients, which are obtained from the graph between different atomic number nuclei and A_Z & B_Z , can be generalized into a single formula that can be used to calculate the α half-life of heavy nuclei.

In this work, we have recalculated the Viola-Seaborg coefficients[1] by observing total of 104 α -decay favoured nuclei for atomic number range of $Z = 88$ to 98 , using the latest NNDC data[2], incorporating the effects of alpha transition intensity and electron screening correlation[3].

Methodology

In 1911, Geiger-Nuttall (GN) established a relationship between α -decay and partial half-life as follows:

$$\log_{10} T_{\frac{1}{2}}^{\alpha} = \frac{A_z}{\sqrt{E_{\alpha}^*}} + B_z$$

Here, A_z and B_z are Z-dependent coefficients, and $T_{\frac{1}{2}}^{\alpha}$ is the experimental half-life of α -decay

and E_{α}^* is effective α -decay energy and is given by:

$$E_{\alpha}^* = \frac{A}{A-4} E_{\alpha} + \Delta E_{SC}$$

Here, ΔE_{SC} is the electron screening correction[4] and is expressed as:

$$\Delta E_{SC} = (6.5 \times 10^{-5}) Z_D^{\frac{7}{5}} \text{ MeV}$$

Here, Z_D is atomic number of daughter nuclei. The partial half-life $T_{\frac{1}{2}}^{\alpha}$ of isotopic nuclei is given as:

$$T_{\frac{1}{2}}^{\alpha} = \frac{T_{\frac{1}{2}}}{\text{B.R.} \times I_{\alpha}}$$

Here, $T_{\frac{1}{2}}$ is the total half-life, B.R. is the branching ratio for α -decay and I_{α} is intensity of ground state to ground state transition. Viola-Seaborg(VS) generalized the GN law to the Viola-Seaborg Formula (VSF) in 1966 by observing straight and nearly parallel lines:

$$\log_{10} T_{\frac{1}{2}}^{\alpha} = \frac{aZ + b}{\sqrt{E_{\alpha}^*}} + (cZ + d) + h_{\log}$$

Here a, b, c, and d are VS coefficients obtained from even-even nuclei, and h_{\log} is the hindrance factor calculated for unpaired nucleons.

Result and Discussion

In this work, A_z and B_z were obtained by observing a regression line graph between $(E_{\alpha}^*)^{-\frac{1}{2}}$ and $\log T_{\frac{1}{2}}^{\alpha}$ for forty even-even nuclei (including their α -decay favoured isotopes) as

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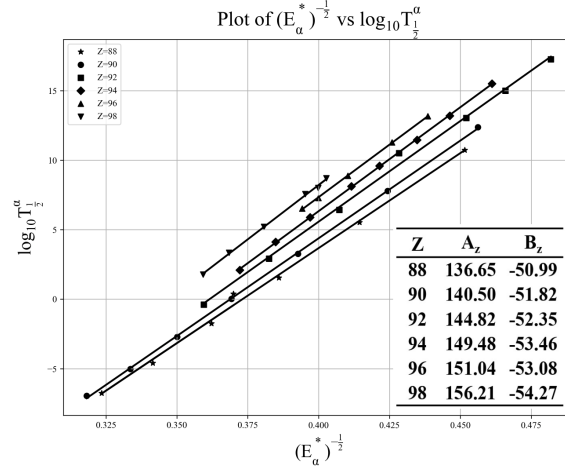


FIG. 1: Regression lines with slope A_z and intercept B_z for even-even nuclei in the range 88 to 98.

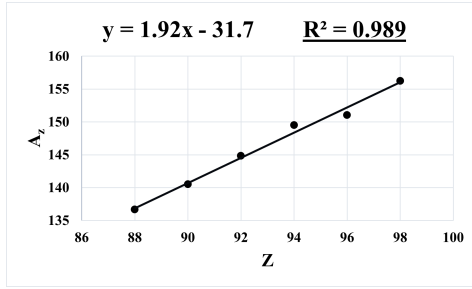


FIG. 2: Z vs A_z plot with slope a and intercept b.

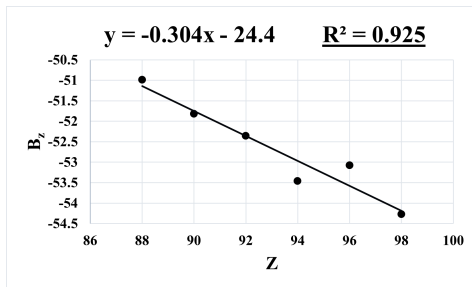


FIG. 3: Z vs B_z plot with slope c and intercept d.

shown in Fig. 1. Viola-Seaborg coefficients a, b, c, and d are calculated from Fig. 2 & Fig. 3. One can clearly observe that regression coefficient R^2 is very close to 1 which was not

the case with NUBASE2016 data[3]. In the same range, h_{\log} was calculated for twenty-six even-odd, twenty odd-even, and sixteen odd-odd nuclei.

Obtained VS formula with coefficients a, b, c and d for isotope of range Z = 88 - 98 is:

$$\log_{10} T_{\frac{1}{2}}^\alpha = \frac{1.92 \times Z - 31.7}{\sqrt{E_\alpha^*}} + (-0.304 \times Z - 24.4) + h_{\log}$$

Calculated mean values of h_{\log} for range Z = 88 - 98 are:

$$h_{\log} = \begin{cases} 0.0000 & \text{for even-Z, even-N} \\ 1.5841 \pm 0.2803 & \text{for even-Z, odd-N} \\ 0.4648 \pm 0.2057 & \text{for odd-Z, even-N} \\ 0.9701 \pm 0.2666 & \text{for odd-Z, odd-N} \end{cases}$$

This VS formula with updated coefficients and h_{\log} can be extrapolated to predict estimate α -decay half life of super-heavy nuclei.

References

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- [4] J.O. Rasmussen, Elsevier, pp. 701-743 (1968)