

Alpha decay from polonium isotopes

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Introduction

Radioactive decay is a natural process in which an unstable nucleus converts into a more stable form by emitting radiation. Among the various forms of nuclear decay, alpha decay is the most prevalent in heavy nuclei, where the nucleus releases a helium particle, resulting in increased stability. The fundamental mechanism behind this process is the quantum tunnelling effect. Alpha decay finds a wide range of applications in both daily life and scientific research. It is utilized in smoke detectors, medical therapies, nuclear power generation, and space energy systems such as radioisotope thermoelectric generators (RTGs). Polonium, a rare and highly radioactive element discovered by Marie and Pierre Curie in 1898, is particularly notable for its tendency to undergo alpha decay. Numerous theoretical frameworks exist to investigate the half-lives of alpha decay[1, 2]. In this study, we employed the Effective Liquid Drop Model(ELDM) to investigate the alpha decay half-lives of the ¹⁸⁶⁻²¹⁸Po isotopes. We compare the experimental half-lives of chosen Po isotopes with the theoretical values obtained from four mass tables (ame2024, ws4, frdm, ktuy), and these results are illustrated in plots.

Theoretical framework

In the Effective Liquid Drop Model, α and cluster decay are explained in a unified framework[3, 4]. In this model, the potential energy (V) contribution includes the Coulomb, surface, and centrifugal components.

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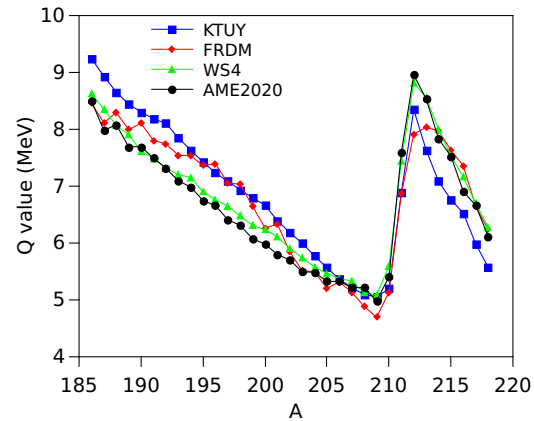


FIG. 1: Q-value of alpha decay from ¹⁸⁶⁻²¹⁸Po isotopes.

The half-life for the decay is obtained as

$$T_{1/2} = \frac{\ln 2}{\lambda} \quad (1)$$

λ is the decay constant. It is calculated using

$$\lambda = \lambda_0 P \quad (2)$$

where λ_0 is the assault frequency ($\lambda_0 \approx 10^{22} s$). approximation,

$$P = \exp\left\{-\frac{2}{\hbar} \int_{\zeta_1}^{\zeta_2} \sqrt{2\mu(V-Q)} d\zeta\right\} \quad (3)$$

where μ is the inertia coefficient, which is obtained using the effective inertia approximation, and Q is the Q-value of the decay process. The limits of integration represent inner and outer turning points.

Results and Discussion

The alpha decay of polonium isotopes within the mass range A=186 to 218 is examined utilizing the Effective Liquid Drop

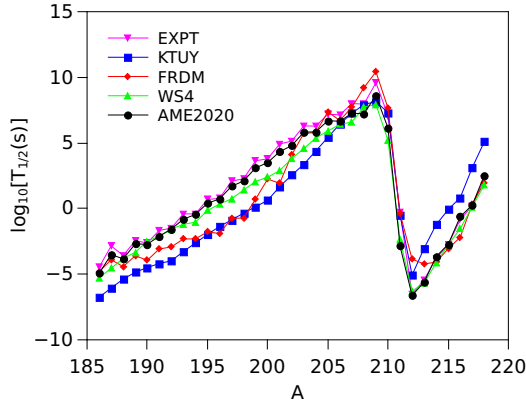


FIG. 2: Half-lives of alpha decay from $^{186-218}\text{Po}$ isotopes.

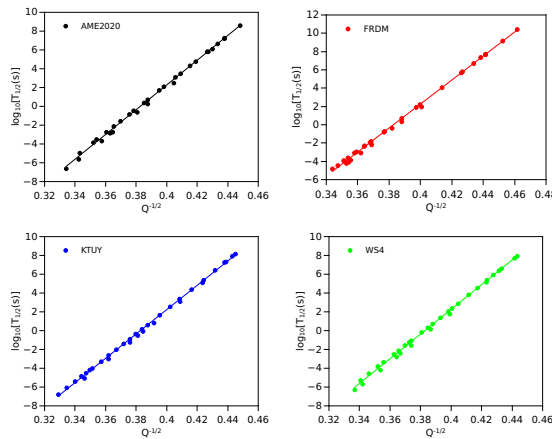


FIG. 3: Geiger-Nuttall plot of alpha decay from $^{186-218}\text{Po}$ isotopes

Model. The Q values and half-lives of these isotopes are computed using four distinct mass tables: AME2020, WS4, FRDM, and KTUY. Furthermore, we possess experimental half-life values for polonium isotopes (186-218)[5].

Fig. 1 presents the Q-value plot of Po isotopes for the four models. As the mass number increases, the Q value gradually decreases, followed by a sudden increase and then a subsequent decrease. Fig 2 illustrates the plot of

alpha decay half-lives for polonium isotopes. The graph shows that as the mass number increases, the half-life also increases, followed by a sudden decline in half-life, after which it increases again. The region where the half-life increases, indicates that the isotopes are becoming more stable, resulting in slower decay due to lower Q values. The Q value plot serves as an inverse reflection of the half-life plot. A peak at A=209 signifies the most stable configuration (parent nuclei), where the neutron number $N = 125$ is close to the magic number 126. The observed dip in half-life near A=210 occurs because the nucleus decays into ^{208}Pb (daughter nuclei), which shows the parent is highly unstable against alpha decay.

To analyse which mass table is best suited for the study, we computed the standard deviation. The lowest standard deviation is observed for AME2020[5], with $\sigma = 0.6242$, while the highest is associated with KTUY. The FRDM and WS4 models fall in between. Consequently, AME2020 emerges as the most precise model.

Fig. 3 illustrates the Geiger-Nuttall plot, which correlates $\log_{10}T_{1/2}$ with the reciprocal of the square root of the Q value for the four models. This relationship is represented as a linear plot. The systematic analysis of alpha decay half-lives and Q-values for Polonium isotopes reveals a significant reliance on nuclear shell effects. In summary, these findings reinforce the notion that alpha decay in heavy nuclei is significantly influenced by shell structure and nuclear binding effects.

References

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