Alpha and Double Alpha Decay of Rn Isotopes

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Introduction

One of the most important ways an unstable radioactive nucleus decays in the heavy and superheavy regions is by alpha decay[1]. Double alpha decay occurs when a nucleus emits two alpha particles at the same time. This process is relatively rare compared to single alpha decay and typically occurs in heavy elements where the nucleus is unstable. Little progress was made in theoretical and experimental investigations for decades following the initial prediction of double alpha decay. Tretyak researched the potential for double alpha emission from 80 naturally occurring nuclei in 2021 [2]. They reported the experimental half-life limit of 2-α emission from ^{209}Bi isotopes for the first time.

Theoretical formalism

A. Effective Liquid Drop Model

In ELDM, proton, α, and cluster decay are explained in a unified framework. These processes are explained by considering different inertial coefficients according to the shape parametrization chosen to explain the dynamical evolution of the system. Four independent coordinates are selected to explain the shape parametrization[3].

The barrier penetrability factor P is calculated using WKB approximation

$$P = exp\{-\frac{2}{\hbar}\int_{\zeta_1}^{\zeta_2}\sqrt{2\mu(V-Q)}d\zeta\} \quad (1)$$

Where μ is the inertia coefficient, which is obtained using effective inertia approximation.

Here the contribution of Coulomb, surface, and centrifugal potential energy is considered. However, the centrifugal component is not included as the angular momentum carried by the alpha particle is very small. The decay constant,

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

where λ_0 is the assault frequency ($\lambda_0 \approx 10^{22}s$). Finally, the half-life for the decay is obtained as

$$T_{1/2} = \frac{ln2}{\lambda} \quad (3)$$

B. Universal Decay Law

The logarithmic half-life of a nucleus undergoing cluster decay (in our case cluster is α) is given by UDL [4] as

$$log_{10}T_{1/2} = aZ_cZ_d\sqrt{\frac{A}{Q}} + b\sqrt{AZ_cZ_d(A_d^{1/3}+A_c^{1/3})} + c \quad (4)$$

where A, A_c and A_d are the reduced mass, the mass of the cluster, and the mass of the daughter respectively. Here the constants are $a = 0.4314, b = -0.4087$ and $c = -27.7725$.

C. Scaling law of Horoi et. al.

Another empirical formula is a scaling law proposed by Horoi[5], which gives the logarithmic half-life as

$$log_{10}T_{1/2} = (a_1\mu^x + b_1)\frac{(Z_cZ_d)^y}{\sqrt{Q}-7} + a_2\mu^x + b_2 \quad (5)$$

where constants are $a_1 = 9.1, a_2 = 7.39, b_1 = -10.2$, $b_2 = -23.2, x = 0.416$ and $y = 0.613$ and $\mu = (A_cA_d)/(A_c + A_d)$. Both semi-empirical formulae apply to alpha decay as well as cluster radioactivity.

Result and Discussion

We conducted an extensive examination of the alpha and double alpha decay half-lives of

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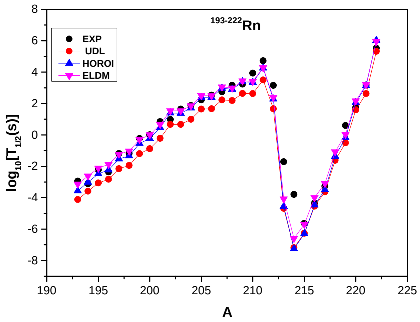

FIG. 1: Alpha emission half lives of of $^{193-222}$Rn.

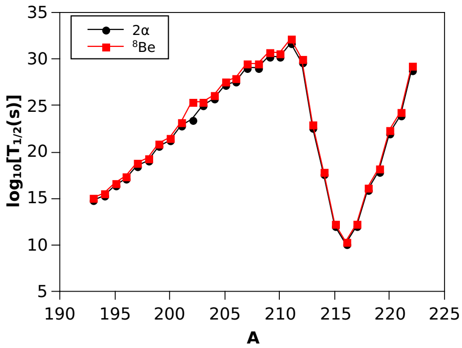

FIG. 2: 2-α and ^{8}Be emission half lives of $^{193-222}$Rn isotopes.

Rn isotopes in the A = 195–222 range. ELDM is chosen for the whole study. To begin with, we have calculated the alpha decay half-lives of the selected isotopes. The Q-value must be positive for a specific decay mode to exist. Q-value of $\alpha-$decay is calculated using

$$Q = \Delta M_p - (\Delta M_d + \Delta M_c) \qquad (6)$$

ΔM_p, ΔM_d, and ΔM_c are the mass excess [6]of the parent, the daughter, and the emitted particle (here alpha), respectively.

The results are compared with the semi-empirical formula UDL and the Scaling law of Horoi et al. and also with the available experimental values. Fig. 1 shows the $\alpha-$decay half-lives of the Rn isotopes. The graph demonstrates that predicted results are reasonably consistent with experimental data. From the graph, we can observe that half-life is maximum when the parent is magic or near to magic neutron number (N=125). Half-life is found to be minimum when daughter nuclei is magic or near magic neutron number. Here it is N=128, which is consistent with other theoretical works [7].

In the next stage, we used ELDM to assess the likelihood of double alpha decay from Rn isotopes. We assessed the half-lives of both double alpha and ^{8}Be emissions. The Q-value (eqn. 6) is calculated using $\Delta M_c = 2\Delta M_\alpha$ and $\Delta M_{^8\mathrm{Be}}$ for double alpha and ^{8}Be decay, respectively. Figure 2 illustrates the comparison of both half lives. Double alpha decay has shorter half-lives than ^{8}Be emission, indicating its greater feasibility. As previously observed, the half-life is highest when the parent is close to magic and lowest when the daughter is magic (N = 126).

Furthermore, the study highlighted the need for advanced detection techniques to observe such rare events, prompting further studies into the underlying physics of nuclear decay.

References

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