Heavy Particle radioactivity and alpha decay in heavy Molybdenum isotopes

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1. Introduction: The heavy nuclei are found to be unstable and undergo different decay modes. The case $A_e = 4$ corresponds to alpha decay; cases in which $A_d = A_e$ correspond to spontaneous fission; and the intermediate case in which $4 < A_e < A_d$, we call heavy particle radio activities. Such a new kind of natural heavy particle radioactivity in which the emitted cluster is heavier than an alpha particle but lighter than a fission fragment was first predicted in 1980 by Sandulescu et al., [1] but it was confirmed experimentally by Rose and Jones [2] from the University of Oxford. Alpha decay was observed by Rutherford about a century ago. The alpha decay theory was formulated by Gamow [3] and independently by Gurney and Condon on the basis of quantum tunnelling. The study of these different decay modes plays a vital role in identifying the heavy and super heavy nuclei. Many theoretical models have been employed to study such decay modes[4, 5]. The half-lives of heavy particle radioactivity and alpha decay of heavy Molybdenum nucleus are systematically calculated using cubic plus Yukawa plus exponential model [6, 7] by including quadruple, hexadecapole, and hexacontatetrapole deformations in the parent nucleus along with the quadruple deformation in the daughter nucleus and predicted the most prominent decay mode. The deformation parameter values are taken from ref[8].

2. Theoretical Frame Work: The stability of heavy Molybdenum isotopes against alpha decay and heavy particle decay have been studied within the framework of cubic plus Yukawa plus exponential model. The amount of energy released in these processes are determined by the following equation,

$$Q = \left[M_p\left(A_p, Z_p\right) - M_d(A_d, Z_d) - M_e(A_e, Z_e)\right] \times 931\, MeV \qquad (1)$$

Here, M_p, M_d, and M_e are the excess mass of the parent, daughter, and emitted cluster nuclei respectively, the mass excess values are taken from Audi et al., [9]. Our model has a cubic potential for the overlapping region which is smoothly connected by a Coulomb and Yukawa plus exponential potential for the region after separation. If the Q-value of the reaction is taken as the origin, the potential for the post -scission region as the function of the centre of mass distance 'r' of the fragment is given by

$$V(r) = V_C(r) + V_n(r) - V_{df}(r) - Q \qquad (2)$$

Here V_C is the Coulomb potential between a spheroidal daughter nucleus and spherical emitted cluster, V_n is the nuclear interaction energy due to finite range effects of Krappe et al., and V_{df} is the change in nuclear interaction energy due to quadruple deformation of the daughter nucleus. For the overlapping region, we approximate the potential barrier by a third-order polynomial suggested by Nix having the form,

$$V(r) = -E_v + [V(r_t) + E_v]\left\{S_d\left(\frac{r-r_i}{r_t-r_i}\right)^2 - S_e\left(\frac{r-r_i}{r_t-r_i}\right)^3\right\} \qquad r_i \le r \le r_t \qquad (3)$$

Expressing the energies in MeV, lengths in fm, and time in seconds for calculating the lifetime of the decay system we use the formula,

$$T = \frac{1.433 \times 10^{-21}}{E_v}\,(1 + \exp(k)) \qquad (4)$$

3. Results and Discussion: We have systematically studied the stability of Molybdenum isotopes decaying via alpha decay and heavy particle decay using the CYE model. All the possible modes of heavy particle decay from the parent isotopes have been investigated and the computed logarithmic half-lives values are compared with the alpha decay half-lives. The comparison of different decay modes of heavy Molybdenum isotopes is shown in figure1. From the calculation, we have found that the half-lives of alpha decay are found to be smaller than that of heavy particle decay.

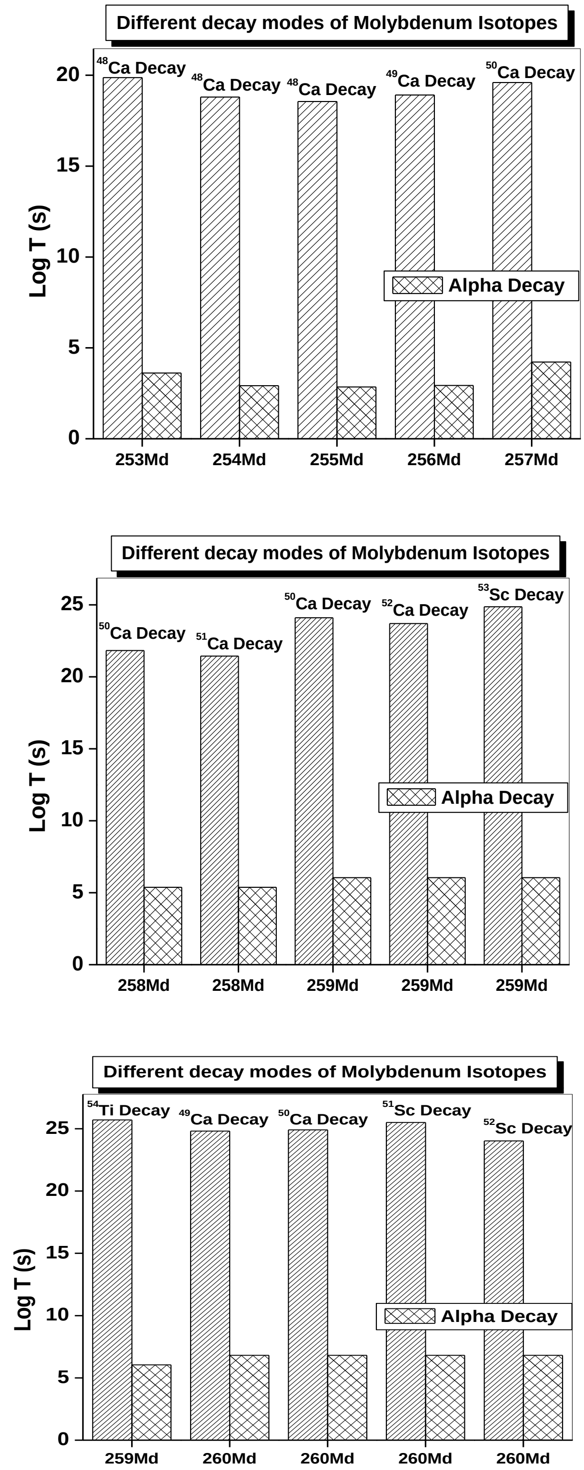

Figure 1. Comparison of different decay modes of $^{253\text{-}260}$Md isotopes.

4. Conclusion: Theoretical studies on the competition between alpha decay and heavy particle decay of heavy Molybdenum isotopes using the CYE model revealed that alpha decay is the most prominent decay mode in the heavy Molybdenum isotopes, since the calculated logarithmic alpha decay half-lives are less than that of the heavy particle decay.

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