Binary and ternary decay dynamics of nuclear systems within fragmentation approach

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1. Introduction

The nuclei belonging to the heavy mass region are highly radioactive and may undergo different binary decay modes such as α decay, cluster radioactivity (CR), heavy particle radioactivity (HPR) and the spontaneous fission (SF). A radioactive nucleus may opt any of these decay modes and the disintegration process depends on different factors such as the shell effect, shape, size, deformation etc. In addition of these decay modes there exist a probability of three fragment emission, and the process is termed as ternary decay. The primary objectives of this work is to make a comparative analysis of different binary decay modes (α-decay, CR, HPR and SF), identification of the binary fission fragments and their comparison with the ternary fission fragments. In the present work, the binary decay analysis is carried out using preformed cluster model (PCM)[1] and three cluster model (TCM)[2] is employed to study ternary decay mechanism. The analysis of the binary decay modes is carried out using the fragmentation potential, preformation probability (P_0), penetration probability (P) and the assault frequency (ν) etc. Similarly, the ternary fission analysis is carried out for the light and heavy third fragment accompanied fission modes. A brief description of the work done during my PhD degree is discussed in the next section:

2. Calculation and results

In this work, a comprehensive study of the alpha particle emergence from $^{188-218}$Po isotopes is carried out within the framework of the preformed cluster model (PCM). The barrier characteristics are studied using two choices of radii (with surface diffuseness (C_i) and without surface diffuseness(R_i))[3]. The α decay is found to be most prominent decay mode in the chosen set of isotopes. The preformation and penetration probability of the decay fragments is studied with respect to increase in the neutron number of the parent nuclei. The alpha decay half lives of Polonium isotopes are calculated using classical assault frequency (ν_c) and quantum mechanical assault frequency (ν_q) and a comparison is made with the experimental data. Further, the alpha decay half-lives of the $^{198-220}$ Rn isotopes are calculated using effective assault frequency (ν_e) parameter and a comparison is made with the available experimental data.

In addition to this, the binary decay analysis of the ^{253}Es radioactive nucleus is carried out using PCM. A comparative study of the probable radioactive decay modes such as α-decay, CR, HPR and SF is carried out in terms of the fragmentation potential, preformation probability (P_0) and penetration probability (P)[4]. The fragmentation structure is explored using two kind of nuclear potentials , i.e., Yukawa plus exponential and proximity potential. The structure of the fragmentation potential and the location of potential minima are found to be independent of the choice of nuclear potential. The decaying fragments and their complementary fragments are found to lie near the shell closure. The decay half-lives ($T_{1/2}$) are calculated for all decay modes by the optimizing the neck length parameter ΔR. The calculated half-lives of α decay and spontaneous fission find nice agreement with the experimental data. Also, the half-lives are predicted for cluster and heavy particle radioactivity, for which experimental verification would be of future interest.

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Further, the role of deformation and orientation in the spontaneous fission (SF) is explored using PCM. The SF analysis of even mass $^{242-260}$Fm isotopes is carried out and the mass distributions is explored[5]. The deformation effects are included upto the quadrupole (β_2) deformed nuclei with optimum orientations ($\theta_i^{opt.}$) leading to hot-compact (side-to-side) and cold-elongated (tip-to-tip) configurations. The spherical and hot-compact deformed configurations of decay fragments result in the symmetric fragment mass distributions for Fm isotopes; however, the symmetric peak gets sharper with an increase in the neutron (N) number of the parent nucleus. In the case of cold orientations, a transition from two-peaked (asymmetric fission) to three-peaked (multimodal fission) mass distribution is observed with an increase in the mass number of Fm isotopes. The SF half-lives ($T_{1/2}^{SF}$) are calculated using the neck-length parameter (ΔR) for $^{242-260}$Fm isotopes and compared with the experimental data.

The light charge particle accompanied fission (ternary fission) mode of the ^{253}Es nucleus is explored using three cluster model (TCM). The calculations are performed using two kinds of nuclear potentials i.e. Yukawa plus exponential and proximity potential[4]. The fragmentation structure is used for the identification of most probable fission fragments. The decay probability of the probable fission fragments seems relatively higher in case of the proximity potential. A comparison of the barrier characteristics for both nuclear potentials is made. In addition to this, comparison of the binary and ternary fission fragments is also carried out. The mass distribution for both kind of decay modes (binary and ternary) is studied and it is observed that the contribution of relative yield is higher in case of binary fission as compared to ternary fission. Further, the role of shell effects is analyzed in binary as well as ternary decay channel.

The ternary fission analysis of two Fm isotopes having atomic mass $A_P = 242$ and 258 is carried out using TCM. First, the choice of third fragment (A_3) is fixed by minimizing the probable A_3 fragments having different proton neutron configurations[6]. Further, the fission fragment combinations ($A_1 + A_2 + A_3$) are identified for the fixed third fragments by selecting the channel of lower ternary fragmentation potential and higher relative fission yield. Two type of tripartition of radioactive nuclei is considered, equatorial cluster tripartition (ECT) and collinear cluster tripartition (CCT). A comparative analysis of ternary fragmentation potential and relative fission yield within ECT and CCT geometrical arrangements is carried out for different choices of third fragment, i.e., $A_3 = 1$ to $A_P/3$. The choice of most probable fragments suggest that the proton and neutron magic shell closures play essential role in the ternary mass division. Finally, a relative analysis of binary and ternary fragmentation is worked out for better insight of the dynamics involved.

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