Cluster decay of heavy nuclei

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Introduction

We study the process of cluster radioactivity where from one parent nucleus (^AZ), one obtains an emitted particle $^{A_e}Z_e$ and a daughter nucleus $^{A_d}Z_d$:

$^AZ \rightarrow {}^{A_e}Z_e + {}^{A_d}Z_d$

and calculate the decay half-life $T_{1/2}$ of the cluster element decay.

An approach we have proposed recently [1] for calculation of decay half-life $T_{1/2}$ on the α decay of radioactive heavy ions is applied to the evaluation of the important $T_{1/2}$ values for the cluster decay.

The potential which simulates the total effective potential of a typical element+daughter system is expressed analytically as a function of radial distance r as follows.

$$V(r) = \begin{cases} V_0[\xi_1 - (\xi_1 - \xi_2)\rho_1(r)], & \text{if } r \leq R_0 \\ V_0\xi_2\rho_2(r), & \text{if } r > R_0 \end{cases} \quad (1)$$

where $\rho_n(r)=[cosh^2\frac{R_0-r}{d_n}]^{-1}$, n=1, 2 and $V_0 > 0$.

This potential can be solved for s-wave exactly, both when the potential is real and when the potential has absorptive imaginary part. The potential has six parameters V_0, ξ_1, ξ_2, R_0, d_1, and d_2 and has been termed as pocket-barrier (PB) potential. It is obvious that different parent nuclei decaying through cluster decay mode would experience different interaction potentials for their corresponding cluster+daughter systems depending on the values of mass number A and atomic number Z of the parent nucleus. The variation in the potential is achieved by changing the value of one of the above parameters namely d_1 while the values of remaining four parameters are fixed at V_0=1 MeV, ξ_1=0, ξ_2=V_{B0}, d_2=1 and r_0=1.035 fm where $R_0 = r_0(A_e^{1/3}+A_d^{1/3})$. The result of the Coulomb barrier height (V_{B0}) for heavy-ion system can be obtained through the parametrized formulas developed recently in [2] by using the double folding model.

A crucial quantity for the accuracy of half-life calculation is the released energy $Q = [M-(M_e+M_d)]c^2$, obtained as difference between the parent M and the two decay product masses, M_e and M_d, in units of energy; c is the velocity of light. The Q values for different systems are obtained by using the masses of the nuclei given in recent mass tables (see Ref. [53] of [3]).

In our calculation, the Q-value of the system is recognised as the resonance energy of the quasi-bound state generated by the effective potential (1) by virtue of a pocket in the interior region $r < R_0$. Using a very small imaginary potential in the interior region r< R_0 as done in [4], the reaction cross section $\sigma_R = \frac{\pi}{k^2}(1- \mid S(k) \mid^2)$ where $S(k)$ and k denote the S-matrix and the wave number, respectively, is calculated as function of energy E. In the variation of σ_R with E, the position of the peak gives the resonance enery which is equal to the Q-value. For a given value of Q equated to the resonance energy, the potential parameter d_1 is varied and the peak in the variation of σ_R is obtained to find the value of d_1 from the positon of the peak. With this, the potential for the decaying system is fully specified. In this situation, the exact wave function is used to calculate the decay life-time through our wave function method described in [1].

In Table I, we record the results of of our present calculation denoted as $T_{1/2}^{(prent)}$ along the experimental values of $T_{1/2}^{(expt)}$ and Q-values given in [3] in the cases of nuclei with Z=90-96. The comparision of the calculated results of $T_{1/2}$ with the corresponding exper-

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imental data reveals excellent explanation of the measured data. The fitting of $T_{1/2}$ of other nuclei available in the literature by our present formulation is in progess. It will be reported soon.

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TABLE I: Results of released energy Q and half-life $T_{1/2}$ from experiment $log_{10}T_{1/2}^{(expt)}$ [3] and calculation $log_{10}T_{1/2}^{(prent)}$ of cluster-decay of heavy nuclei obtained using present formulation where values of potential parameters V_0=1 MeV, ξ_1=0, d_2=1 and r_0=1.035 fm are kept same for all nuclei. In columns 5 and 6, values of parameter d_1 and Coulomb barrier height V_{B0} are given, respectively.

Transition	Q (MeV)	$log_{10}T_{1/2}^{expt}$ (sec)	$log_{10}T_{1/2}^{prent}$ (sec)	d_1 (fm)	V_{B0} (MeV)
$^{231}Pa \rightarrow {}^{207}Ti + {}^{24}Ne$	60.41	22.89	23.05	1.1809	89.667
$^{230}U \rightarrow {}^{208}Pb + {}^{22}Ne$	61.39	19.57	22.25	1.2646	91.196
$^{232}U \rightarrow {}^{208}Pb + {}^{24}Ne$	62.31	20.39	21.33	1.3246	90.709
$^{233} \rightarrow {}^{209}Pb + {}^{24}Ne$	60.49	24.84	25.68	1.2005	90.644
$^{233}U \rightarrow {}^{208}Pb + {}^{25}Ne$	60.73	24.84	25.68	1.0122	90.476
$^{234}U \rightarrow {}^{210}Pb + {}^{24}Ne$	58.83	25.93	26.42	1.0880	90.580
$^{234}U \rightarrow {}^{206}Hg + {}^{28}Mg$	74.11	25.53	25.23	1.2525	105.30
$^{236}Pu \rightarrow {}^{208}Pb + {}^{28}Mg$	79.66	21.52	21.38	1.2816	107.78
$^{238}Pu \rightarrow {}^{210}Pb + {}^{28}Mg$	75.91	25.57	25.60	1.0696	107.62
$^{238}Pu \rightarrow {}^{206}Hg + {}^{32}Si$	91.19	25.28	24.22	1.2171	121.73
$^{242}Cm \rightarrow {}^{208}Pb + {}^{34}Si$	96.51	23.15	21.65	1.2407	124.07

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