Shell closure effects associated with tin daughter

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Introduction

The radioactive decay of nuclei emitting particle heavier than alpha particle termed as exotic decay or cluster radioactivity was first predicted by Sandulescu et al [1] in 1980 on the basis of Quantum Mechanical Fragmentation Theory (QMFT). Experimentally Rose and Jones [2] first observed such decays in 1984 in the radioactive decay of ^{223}Ra by the emission of ^{14}C. Now, there is a whole family of such disintegration modes: ^{14}C radioactivity; ^{24}Ne radioactivity; ^{28}Mg radioactivity and so on. Heavy- ions i.e. nuclei heavier than the alpha nucleus called, clusters are emitted spontaneously in decays of Radium (Ra), Actinium (Ac) and other heavier actinides up to plutonium (Pu). The heaviest cluster observed so far is ^{32}Si emitted from ^{238}Pu parent nucleus.

In spherical nuclei the $1g_{9/2}$ orbital is distinctly separated in energy from all other single-particle levels. This gives rise to the well established magicity of the neutron and proton numbers N, Z =50 and points towards a somewhat less pronounced closure at N, Z =40. For protons the Z=40 sub shell closure is clearly demonstrated in [3] by histogram by using PCM model.

The shell closure effects in nuclei via cluster decay have been studied. In this context, here we have used the preformed cluster model (PCM) of Gupta and collaborators based on quantum-mechanical fragmentation theory. The key point in the cluster radioactivity is that it involves the interplay of close shell effects of parent and daughter nuclei. Small half-life for a parent indicates the shell stabilized daughter and long half-life indicates the stability of the parent against the decay. In the cluster decay of trans-lead nuclei observed so far, the end product is doubly magic lead for its neighboring nuclei. We have extended the idea of cluster radioactivity. We have investigated here the decay of $^{118-132,140-170}$Ce nuclei where Tin is taken as a daughter nucleus.

Preformed Cluster Model

The preformed cluster model (PCM) [4] uses the dynamical collective coordinates of mass and charge asymmetries η and η_z on the basis of Quantum Mechanical Fragmentation Theory. The decay constant λ in PCM is defined as

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P \qquad (1)$$

Here P_0 is the cluster preformation probability and P is the barrier penetrability which refer, respectively, to the η- and R- motions. ν_0 is the barrier assault frequency. P_0 are the solutions of the stationary Schrodinger equation in η,

$$\left\{-\frac{{}^{2}}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta)\right\}\psi^{(\nu)}(\eta)=E^{(\nu)}\psi^{(\nu)}(\eta) \qquad (2)$$

Which on proper normalization are given as

$$P_0 = \sqrt{B_{\eta\eta}}\left|\psi^{(0)}\left(\eta\left(A_i\right)\right)\right|^2\left(2/A\right) \qquad (3)$$

The fragmentation potential ($V_R(\eta)$) in eq (2) is calculated simply as the sum of Coulomb interaction, the nuclear proximity potential and the ground state binding energies of two nuclei:

$$V(R_a,\eta) = -\sum_{i=1}^{2} B(A_i,Z_i) + \frac{Z_1 Z_2 e^2}{R_a} + V_P \qquad (4)$$

With B's taken from the 2003 experimental compilation of Audi et al and from the 1995 calculations of Moller et al. Thus, full shell effects are contained in our calculations that come from the experimental and/or calculated binding energies.

The WKB tunneling probability calculated is P= $P_i P_b$ with

$$P_i = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_i}\{2\mu[V(R)-V(R_i)]\}^{1/2}dR\right]$$

$$P_b = \exp\left[-\frac{2}{\hbar}\int_{R_i}^{R_b}\{2\mu[V(R)-Q]\}^{1/2}dR\right]$$

These integrals are solved analytically for R_b, the second turning point, defined by $V(R_b)$=Q-value for the ground- state decay.

The assault frequency ν_0 is given siply as

$$\nu_0 = \left(\frac{2E_2}{\mu}\right)^{1/2} \Big/ R_0 \qquad (7)$$

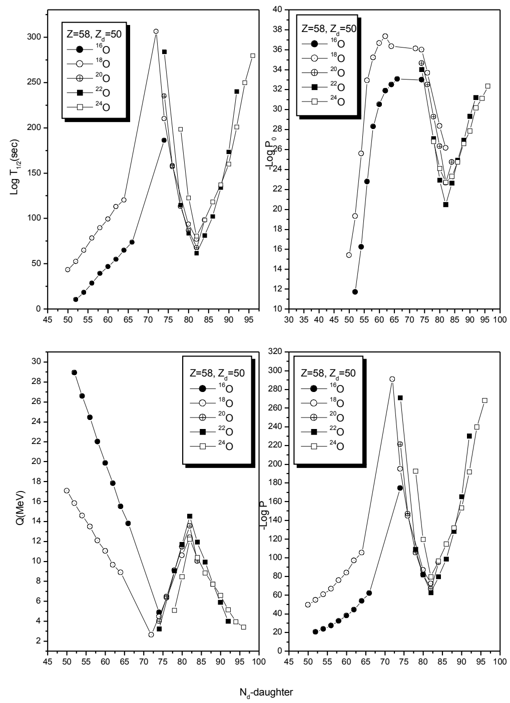
With $E_2=(A_1/A)Q$, the kinetic energy of lighter fragment, for the Q- value shared between the two products as inverse of their masses.

Calculation and Results

The closed shells (spherical and or deformed) associated with Sn daughter are investigated. The decay characteristics i.e., Q- values, preformation probabilities and penetration probabilities are plotted as a function of daughter neutron number. From the figure it is clearly shown that the cluster decay half-lives are minimum at the closed shell (here N_d=50 and 82) which is well known as a spherical shell.

For the oxygen cluster decay, various parents of $^{118-132,140-170}$Ce nuclei are considered which gives Sn daughter with different neutron number. Only those clusters are taken which gives positive Q values. In the figure, the penetration and preformation probabilities of different clusters ($^{16-18-20-22-24}$O) shows the minima at the magic number N=50 and N=82. Some of the oxygen clusters are experimentally observed and some are taken for the theoretical calculations.

From the figure, minimum half-lives of various parents indicate the stability of the daughter nuclei i.e. ^{100}Sn and ^{132}Sn. This is more stable against the cluster decay.



References

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