Studies on the alpha decay of Pb isotopes

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Introduction

Alpha decay is a type of radioactive decay in which an unstable nucleus decays through the emission of an alpha particle. The phenomenon was discovered by Rutherford in 1899 and in 1928, on the basis of quantum tunneling George Gamow gave a theoretical explanation to alpha decay process.

In the case of heavy and superheavy nuclei, alpha decay is identified as the most important decay mode as it can give information regarding the nuclear structure. In the present paper we have studied the behavior of the isotopes of Pb against alpha decay and have thus verified the role of neutron shell closure in these decays. Within the Coulomb and Proximity Potential Model (CPPM) proposed by Santhosh et al. [1, 2], we have calculated alpha decay half lives of Pb (Z = 82) isotopes in the region 178 ≤ A ≤ 220 for all the transitions with minimum angular momentum transfer.

The Coulomb and Proximity Potential Model (CPPM)

The potential energy barrier in CPPM is taken as the sum of Coulomb potential, proximity potential and centrifugal potential, for the touching configuration and for the separated fragments. For the pre-scission region, a simple power law interpolation was used. The inclusion of proximity potential reduces the height of the potential barrier.

The interacting potential barrier for two spherical nuclei is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2} \qquad (1)$$

Here Z_1 and Z_2 are the atomic numbers of the daughter and emitted cluster, 'z' is the distance between the near surfaces of the fragments, 'r' is the distance between fragment centers, ℓ represents the angular momentum, μ the reduced mass, V_P is the proximity potential given by Blocki *et al.*,

Using one dimensional WKB approximation, the barrier penetrability P is given as

$$\mathrm{P} = \exp\left\{ -\frac{2}{\hbar} \int_a^b \sqrt{2\mu(V-Q)}\, dz \right\} \qquad (2)$$

The turning points "a" and "b" are determined from the equation, $V(\mathrm{a}) = V(\mathrm{b}) = Q$. The half life time is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda} \right) = \left(\frac{\ln 2}{\nu P} \right) \qquad (3)$$

where, $\nu=(\omega/2\pi)= (2E_v/h)$, represents the number of assaults on the barrier per second and λ the decay constant. E_v, is the empirical vibration energy.

Results and Discussions

The alpha decay properties of the isotopes of Pb within the range 178 ≤ A ≤ 220 have been studied by evaluating the decay half lives using CPPM. The energy released in the alpha transitions is given as

$$Q = \Delta M_p - (\Delta M_\alpha + \Delta M_d) + k(Z_p^\varepsilon - Z_d^\varepsilon) \qquad (4)$$

where ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and alpha particle respectively. The Q values are evaluated using the mass excess values taken from Wang et al. The term $k(Z_p^\varepsilon - Z_d^\varepsilon)$ represents the screening effect of atomic electrons, where k = 8.7eV , ε = 2.517 for Z ≥ 60 and k = 13.6eV, ε = 2.408 for Z < 60. The angular momentum transfer during alpha emission have also been considered and the values are obtained from the spin-parity selection rule given as,

$$\left| J_i - J_j \le \ell \le J_i + J_j \right| \text{ and } \left(\pi_i / \pi_j \right) = (-1)^\ell \qquad (5)$$

where J_i, J_j, π_i and π_j are the spin and parity of the parent and daughter nucleus respectively.

It is to be noted that, in a radioactive decay process, a high value of half life indicates the magicity of corresponding parent nuclei and a low value indicates the magicity of the corresponding daughter nuclei. The role of ^{208}Pb and its neighbouring nuclei in cluster decay have already been revealed through several theoretical studies. The present work aims at analysing the behaviour of Pb isotopes to alpha decay. The calculations and the comparisons have been comprehended in Table 1. The decay half lives for the respective alpha decays have been evaluated within CPPM and also within CPPM with modified assault frequency, explicitly denoted as CPPM1. On comparison with the experimental alpha half lives, it can be found that the half lives evaluated using both our formalisms are in good agreement with the experimental data.

The alpha half life calculations have also been done using the Universal curve (UNIV) of Poenaru et al., the analytical formulae of Royer and the Universal decay law of Qi et al.

A further comparison of our values with the values evaluated using these three theoretical models shows that our values matches well with these theoretical model calculations.

The plots for $\log_{10}(T_{1/2})$ against the neutron number of the daughter nuclei of the alpha emissions from the isotopes of Pb are shown in figure 1. It can be clearly seen from the figure that the maximum half life is for the daughter ^{205}Hg which corresponds to the parent nuclei ^{207}Pb (Z = 82, N = 125), nearly doubly magic. The $\log_{10}(T_{1/2})$ has the minimum value for the decay leading to the daughter ^{206}Hg (Z = 80, N = 126). Both these observations indicates the role of neutron shell closure in alpha decay.

Conclusions

Within CPPM a detailed examination of the alpha decay from Pb isotopes have been performed. Our study reveals that the computed alpha decay half lives are in good agreement with the experimental values and also with the values evaluated using other theoretical models. Through our study we have demonstrated the influence of the neutron shell closure N = 126, on the alpha decay half lives.

Table 1: Comparison of the alpha half lives of $^{178\text{-}192}$Pb isotopes with the experimental data.

Parent nuclei	$T_{1/2}$ (s)		
	Expt.	CPPM	CPPM 1
^{178}Pb	$1.20\text{x}10^{-4}$	$4.03\text{x}10^{-4}$	$2.72\text{x}10^{-3}$
^{179}Pb	$3.50\text{x}10^{-3}$	$2.59\text{x}10^{-3}$	$1.60\text{x}10^{-2}$
^{180}Pb	$4.20\text{x}10^{-3}$	$6.01\text{x}10^{-3}$	$3.80\text{x}10^{-2}$
^{181}Pb	$3.60\text{x}10^{-2}$	$3.91\text{x}10^{-2}$	$2.27\text{x}10^{-1}$
^{182}Pb	$5.61\text{x}10^{-2}$	$9.55\text{x}10^{-2}$	$5.62\text{x}10^{-1}$
^{183}Pb	$5.94\text{x}10^{-1}$	$4.63\text{x}10^{-1}$	$2.49\text{x}10^{0}$
^{184}Pb	$6.13\text{x}10^{-1}$	$1.09\text{x}10^{0}$	$6.02\text{x}10^{0}$
^{185}Pb	$1.85\text{x}10^{1}$	$3.31\text{x}10^{0}$	$1.70\text{x}10^{1}$
^{186}Pb	$1.21\text{x}10^{1}$	$1.65\text{x}10^{1}$	$8.56\text{x}10^{1}$
^{187}Pb	$1.53\text{x}10^{2}$	$1.65\text{x}10^{3}$	$1.78\text{x}10^{4}$
^{188}Pb	$2.70\text{x}10^{2}$	$5.62\text{x}10^{2}$	$2.69\text{x}10^{3}$
^{189}Pb	$3.90\text{x}10^{3}$	$1.09\text{x}10^{4}$	$4.71\text{x}10^{4}$
^{190}Pb	$1.78\text{x}10^{4}$	$4.78\text{x}10^{4}$	$2.11\text{x}10^{5}$
^{191}Pb	$7.98\text{x}10^{5}$	$8.66\text{x}10^{5}$	$3.61\text{x}10^{6}$
^{192}Pb	$3.56\text{x}10^{6}$	$1.62\text{x}10^{7}$	$6.48\text{x}10^{7}$

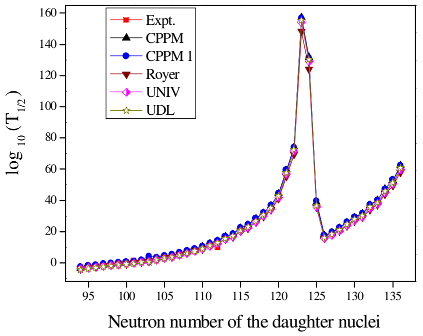

Fig.1. The comparison of the calculated alpha decay half lives of Pb isotopes

References

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