Studies on alpha and double alpha decay in $^{221-247}Pu$ isotopes

Megha Chandran[1], Anusree Radhakrishnan[1] and K. P. Santhosh[1,2,*]
[1]Department of Physics, University of Calicut, Kerala 673635, India
[2]School of Pure and Applied Physics, Kannur University, Swami Anandatheertha Campus, Payyanur 670327, Kerala, India
* email: drkpsanthosh@gmail.com

Introduction

The alpha decay is one of the prominent decay modes of nuclei in the heavy and superheavy regions. The simultaneous emission of two alpha (2α) particles from a radioactive nucleus is known as double alpha decay. The concept of spontaneous emission of 2α particles from a nucleus was first predicted by Poenaru et al.,[1] in 1985. There have not been many studies both theoretical and experimental to understand the possibility of the emission of 2α particles, after its first prediction. Recently in 2021, Tretyak [2] studied the possibility of double alpha emission from 80 naturally abundant nuclei. The author also reported, for the first time, the experimental half-life limit for 2α emission from ^{209}Bi isotopes. By analyzing the data taken from the experiment conducted by Marcillac et al.,[3] to observe single α decay from ^{209}Bi, Tretyak set the experimental limit for 2α emission from ^{209}Bi as $T_{1/2} > 2.9 \times 10^{20}$ y. Very recently one of us (KPS) [4] studied the possibility of 2α decay from ^{209}Bi and the predicted half-life using the SemFIS formula is compared with the reported experimental half-life limit.

In the present work, we aim to study the possibilities of single α and 2α emissions from $^{221-247}Pu$ isotopes using the well-known Universal Decay Law (UDL) of Qi et al.,[5] for alpha and cluster radioactivity.

Universal Decay Law (UDL)

The expression for Universal Decay Law is written as,

$$\log_{10}(T_{1/2}) = aZ_cZ_d\sqrt{A/Q_c} + b\sqrt{AZ_cZ_d(A_d^{1/3}+A_c^{1/3})} + c \quad (1)$$

Where A_c, A_d, Z_c, Z_d are mass number of cluster, mass number of parent, proton number of cluster and proton number of daughter respectively. The constants are a = 0.3949, b = -0.3693, c = -23.7615 and $A = A_cA_d/(A_c + A_d)$.

Results and discussion

The single α and 2α decay are energetically possible only if $Q > 0$. The decay energy or the Q value for α and 2α decay is given by the equation,

$$Q = \Delta M_p - (\Delta M_c + \Delta M_d), \quad (2)$$

where ΔM_p, ΔM_c and ΔM_d are the mass excess of parent, cluster and daughter nuclei respectively. For α decay, $\Delta M_c = \Delta M_\alpha$ and for 2α decay, $\Delta M_c = 2\times\Delta M_\alpha$, where ΔM_α is mass excess of alpha particles. The mass excess values are added from the recent mass table of Wang et al., [6].

The computed Q value for both α and 2α emission $^{221-247}Pu$ are positive indicating the possible emission of both particles from these isotopes. In this study we assume that the highly correlated two alpha particles form a cluster within the parent nuclei, penetrate through the barrier and after crossing the barrier emit two alpha particles. We have computed the half-lives for α and 2α emission from these isotopes using the UDL formula eqn. (1). Figure 1 represents the logarithm of predicted half-lives for single alpha decay (blue circle) and double alpha decay (red star). As the present upper limit for measurement is 10^{30} s, all predicted alpha decay half-lives are within the measurable limit but double alpha decay from $^{221-232}Pu$ are measurable. In Table 1 we tabulated the half-lives for double alpha decay from $^{221-232}Pu$. Table 2 gives comparison of predicted alpha half-lives with corresponding experimental data

[7]. It can be seen that our predicted logarithm of alpha half-life values are in good agreement with experimental data with standard deviation = 0.45. Our observation on decay of $^{221\text{-}232}$Pu will serve as a guide for future experiments on double alpha decay.

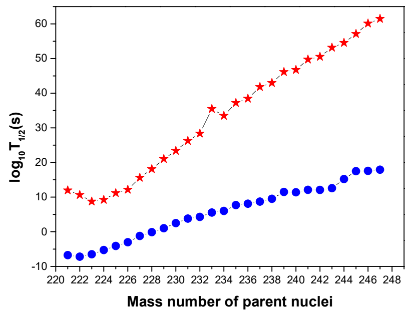

Fig. 1 Graph connecting predicted $\log_{10}T_{1/2}$(s) versus mass number of parent nuclei for single alpha and double alpha decay from $^{221\text{-}247}$Pu isotopes. Blue circle and red star represent single and double alpha decay respectively.

Table 1 The Computed Q value and half-lives for double alpha decay from $^{221\text{-}232}$Pu isotopes.

Parent Nuclei	Daughter Nuclei	$Q_{2\alpha}$ value (MeV)	$\log_{10}T_{1/2}$(s) Present
^{221}Pu	^{213}Th	18.96017	11.96093
^{222}Pu	^{214}Th	19.51517	10.63326
^{223}Pu	^{215}Th	20.34917	8.753466
^{224}Pu	^{216}Th	20.12117	9.218781
^{225}Pu	^{217} Th	19.24417	11.17328
^{226}Pu	^{218}Th	18.41317	12.15346
^{227}Pu	^{219}Th	17.46017	15.60335
^{228}Pu	^{220}Th	16.56817	18.08625
^{229}Pu	^{221}Th	15.60017	21.02378
^{230}Pu	^{222}Th	14.87917	23.39071
^{231}Pu	^{223}Th	14.07417	26.25163
^{232}Pu	^{224}Th	13.51517	28.38043

Table 2 Comparison of computed alpha decay half-lives with corresponding experimental data.

Parent Nuclei	Q_{α} value (MeV)	$\log_{10}T_{1/2}$ (s)	
		Present	Expt.
^{228}Pu	7.940084	-0.12852	0.322219
^{230}Pu	7.178084	2.486070	2.021189
^{236}Pu	5.867184	8.101714	7.955157
^{238}Pu	5.593184	9.512306	9.442094
^{239}Pu	5.244484	11.49089	11.88127
^{240}Pu	5.255784	11.40887	11.31606
^{242}Pu	4.984284	12.06974	13.07313
^{244}Pu	4.665584	15.20996	15.40993

Acknowledgements

The author K.P.S would like to thank the Council of Scientific and Industrial Research, Government of India, for the financial support under the scheme "Emeritus Scientist, CSIR", No. 21(1154)/22/EMR-II dated 20-05-2022.

References

[1] D. N. Poenaru and M. Ivascu, J. Physique Lett. **46**, 591 (1985).
[2] V. I. Tretyak, Nucl. Phys. At. Energy **22**, 121 (2021).
[3] P. de Marcillac, N. Coron, G. Dambier, J. Leblance and J. P. Moalic, Nature **422**, 876 (2003).
[4] K.P.Santhosh and Tinu Ann Jose, Phys. Rev. C **104**, 064604 (2021)
[5] C. Qi, F. R. Xu, R. J. Liotta and R. Wyss, Phys. Rev. Lett. **103**, 072501 (2009).
[6] M. Wang, G Audi, F. G. Kondev, W. J. Huang, S. Naimi and X. Xu, Chinese Phys. C **41**, 030003 (2017).
[7] F. G. Kondev, M. Wang, W. J. Huang, S. Naimi and G. Audi, Chinese Phys. C **45**, 030001 (2021).