FINE STRUCTURE IN CLUSTER RADIOACTIVE DECAYS

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Introduction

The emission of α-particle is an age old known process, which is also called as alpha decay where a small nucleus is emitted from a bigger nucleus. The spontaneous decay of radioactive nuclei with the emission of fragments heavier than α-particle, is termed as Cluster Radioactivity or Exotic Decay. The discovery of fine structure in the ^{14}C decay of ^{223}Ra was made by Brillard et al. [1]. This discovery has provided an evidence for ^{14}C fine structure emission in ^{223}Ra decay. Surprisingly the spectrum obtained by them has revealed that the ^{209}Pb ground state is only weakly fed (15%), whereas the first and second excited states are populated with respective 81% and 4% branching ratios. The experimentally observed logarithm of half lifetime values for such decay at ground state disagrees with the values calculated by most of the theoretical models. This is due to the reason that those models do not take into account the population of the ^{209}Pb excited states.

Soon after the discovery of Brillard et al., Hussonnois et al. [2] obtained a fine structure spectrum for the ^{14}C decay of ^{222}Ra. They performed measurements of the ^{14}C energy spectrum of ^{222}Ra with an intense ^{230}U source, combined with a long counting run with the superconducting magnetic spectrometer facility at Orsay. The fine structure spectrum obtained by them has revealed that the ^{208}Pb daughter is populated with ground and collective octupole $I^{\pi} = 3^{-}$ first excited states. The discovery of such fine structure in the ^{14}C decay of ^{222}Ra and ^{223}Ra has revived the idea that there might exist a similitude between ^{14}C and alpha emissions. A theoretical study of fine structure in the experimentally measured cluster decays and also as-yet unmeasured decays are initiated in this work.

The Method

The unified decay constant for various cluster emissions populated to daughter ground and excited states [3] are evaluated using the formula.,

$$\lambda_{theor} = \frac{\upsilon}{2R_i} S_a^{(a-1)/3} \exp(-2I) \qquad (1)$$

Where $v/2R_i$ is the frequency factor, S_a is the spectroscopic factor and I is the Gamow factor.

The tunneling energy E_{aA} is given by

$$E_{aA} = (M_{A+a}-M_A-M_a)c^2 - E^{ex} \qquad (2)$$

The half- life is then given by

$$T_{1/2} = \frac{\ln 2}{\lambda_{theo}} \qquad (3)$$

The values for LogT obtained by this method have been compared with the available experimental results. The calculated theoretical and experimental results agree generally within a factor of 5. The null entries on the table indicate the decays of as–yet unmeasured modes. It is seen from the table that the probability of decay to excited states is small but finite compared with the decay to the ground state. This preliminary study, if extended by a realistic theoretical model, should yield more information about the excited states of daughter nuclei.

TABLE: Calculated logarithm of life time values for the cluster radioactive decays from parent nuclei to daughter nuclei which are in the ground state and in selected excited states showing fine structure.

Decay Mode			E_{aA}	Logarithm of half-life time $Log_{10}T_{1/2}$(sec.)	
Parent ^{A+a}X	**Cluster** ^{a}z	**Daughter** ^{A}Z	**(MeV)**	**CALC.**	**EXPT.[*ref*]**
^{221}Ra	^{14}C	$^{207}Pb_0$	32.50	13.0	13.4 [7]
		$^{207}Pb_1$	31.93	14.0	
		$^{207}Pb_2$	31.60	14.6	>14.4 [7]
^{222}Ra	^{14}C	$^{208}Pb_0$	33.15	12.11	11.2 [6]
		$^{208}Pb_1$	30.63	16.73	>13.3 [6]
^{223}Ra	^{14}C	$^{209}Pb_0$	31.96	13.8	16.0 [2]
		$^{209}Pb_1$	31.18	15.3	15.2 [2]
		$^{209}Pb_2$	30.54	16.5	16.5 [2]
^{225}Ac	^{14}C	$^{211}Bi_0$	30.59	17.3	17.2 [7]
		$^{211}Bi_1$	30.19	18.1	
		$^{211}Bi_2$	29.83	18.9	
^{229}Th	^{14}C	$^{215}Po_0$	27.22	25.7	
		$^{215}Po_1$	26.94	26.3	
		$^{215}Po_2$	26.92	26.4	
^{229}Th	^{20}O	$^{209}Pb_0$	43.57	24.0	
		$^{209}Pb_1$	42.79	25.4	
		$^{209}Pb_2$	42.15	26.6	
^{231}Pa	^{24}Ne	$^{207}Tl_0$	60.61	22.2	23.2 [4]
		$^{207}Tl_1$	60.26	22.7	23.4 [7]
		$^{207}Tl_2$	59.27	24.1	
^{233}U	^{24}Ne	$^{209}Pb_0$	60.69	23.2	24.8 [5]
		$^{209}Pb_1$	59.91	24.3	24.8 [7]
		$^{209}Pb_2$	59.27	25.2	

The suffixes 0, 1 and 2 denote the ground first and the second excited states.

References

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