Cluster Decay Half Lives of Th-Isotopes using Relativistic Mean Field Model

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Introduction

Cluster radioactivity or Heavy -ion radioactivity is the process in which an unstable nucleus emitted a charged particle that is heavier than alpha-particle but lighter than fission fragments. Cluster decay from medium heavy ion was suggested by Sandulesce et.al theoretically [1]. Latter spontaneous emission of ^{18}O from ^{226}Th was observed by D.N Poenaru et.al experimentally [2]. After this lots of experiments are carried out and it is found that half-life is sensitive towards orbital angular momentum L and also compatible with Q-value. Here we use relativistic mean field (RMF) theory to calculate the Q-values using NL3* and NL-SH force parameter sets. These Q-values are then used to determine alpha decay half-life and cluster decay half-life of Th -isotopes using Viola-Seaberg, Royer analytical formulae, and Universal Decay law

[2].

Theoretical Formalism:

Relativistic mean-field formalism:

RMF theory is based on Lagrangian density containing nucleons interacting with σ, ω, and ρ-meson fields. The relativistic Lagrangian density is given as [3-5]:

$$\mathcal{L} = \overline{\psi_i}\,(i\gamma^{\mu}\partial_{\mu} - M)\psi_i + \frac{1}{2}\partial^{\mu}\sigma\partial_{\mu} - \frac{1}{2}m_{\sigma}^{2}\sigma^{2} - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi_i}\,\psi_i\,\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_{\omega}^{2}V^{\mu}V_{\mu} + \frac{1}{4}c_3\left(V^{\mu}V_{\mu}\right)^2 - g_{\omega}\overline{\psi_i}\,\gamma^{\mu}\psi_i V_{\mu} - \frac{1}{4}\overrightarrow{B^{\mu\nu}}.\overrightarrow{B_{\mu\nu}} + \frac{1}{2}m_{\rho}^{2}\overrightarrow{R^{\mu}}.\overrightarrow{R_{\mu}} - g_{\rho}\overline{\psi_i}\,\gamma^{\mu}\vec{\tau}\,\psi_i.\overrightarrow{R^{\mu}} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\,\overline{\psi_i}\,\gamma^{\mu}\frac{(1-\tau_{3i})}{2}\psi_i A_{\mu} \quad \text{......................(1)}$$

All the quantities have their usual well-known meanings. From the above Lagrangian, we obtained the field equations for nucleons and mesons. These equations are solved by expanding the upper and lower components of the Dirac spinors and the boson fields in an axially deformed harmonic oscillator basis, with an initial deformation factor β_0 . The set of coupled equations is solved numerically by the self-consistent iteration method. We use well accepted NL3* and NL-SH parameter sets. The Q-values can be calculated from binding energies of parent nuclei, daughter nuclei, and emitted clusters i,e,

$$Q = M(A,Z) - M_d(A_d, Z_d) - M_e(A_e, Z_e)$$

Where M(A, Z), $M_d(A_d,$ Zd), and $M_e(A_e,\ Z_e)$ are atomic masses of a parent, daughter, and emitted cluster respectively [1,2].

Viola-Seaborg (VS) Formula

The alpha-decay half-life is calculated from Viola-Seaborg and the expression given by,

$$\log_{10} T_{1/2} = (\text{ a Z+ b})Q^{-1/2} + \text{ c Z + d+ } h_{log}$$

Where Z is the atomic number of the parent nucleus and the Q-value is in Mev. The parameters a=1.66175,b= -8.5166,c= -0.20228 and d= -33.9060 are constants and h_{log} values are given by

h_{log} = 0 for Z,N even
= 0.772 ,for Z odd, N even
= 1.066, for Z even,N odd
= 1.114, for Z,N odd

Royer analytical formula (Royer)

By using Royer analytical formula, the half-life of alpha decay for different isotopes of

Th-isotopes is also studied here. The analytical formula for the decay half-lives of alpha radioactivity for the heavy elements is given as,

$$\log_{10} T_{1/2}(s) = -26.06 - 1.114A^{1/6}\sqrt{Z} + \frac{1.5837\, Z}{\sqrt{Q_\alpha}},$$

Where A is the mass number and Z is the charge number of parent nuclei. Q_α represents the energy released during the reaction [6].

Universal decay law (UDL)

The half-life expression to study cluster decay is given as

$$\log_{10} T_{1/2} = aZ_eZ_d\sqrt{\frac{A}{Q_e}} + b\sqrt{AZ_eZ_d(A_d^{1/3} + A_e^{1/3})} + c,$$

Where $A = \frac{A_dA_e}{(A_d+A_e)}$, and a= 0.3671, b= -0.3296, and c= - 26.2681 [6, 7].

The Q- values and half-life of alpha -decay and cluster decay are given in Table-1 and Table-2 for the emission of various clusters from $^{210-218}Th$-isotopes.

Table-1: Alpha-decay of Th-isotopes.

Parent nuclei	Emitted cluster	$log_{10}(T_{1/2})$ (V-S)			$log_{10}(T_{1/2})$ (Royer)		
		NL3*	NLSH	FRDM	NL3*	NLSH	FRDM [8]
^{210}Th	He	1.75	2.57	-1.51	2.61	3.43	-0.69
^{212}Th	He	4.78	3.85	-2.12	5.63	4.69	-1.34
^{214}Th	He	7.34	5.27	-0.78	8.18	6.09	0.78
^{216}Th	He	2.61	2.93	-1.64	3.35	3.68	-0.94
^{218}Th	He	-6.97	-5.19	-7.86	-6.37	-4.57	-7.26

Table -2: Cluster decay of Th-isotopes:

Emitted cluster	$log_{10}(T_{1/2})$ (UDL)		
	NL3*	NLSH	FRDM
^8Be	51.10	71.20	37.72
^{12}C	25.03	29.37	15.58
^{16}O	30.35	33.17	18.37
^8Be	63.17	56.84	37.33
^{12}C	-19.02	-5.19	-17.41
^{16}O	34.60	44.90	19.42
^8Be	69.21	79.82	25.14
^{12}C	17.11	32.60	17.06
^{16}O	37.65	39.42	20.91
^8Be	63	71.90	38.15
^{12}C	29.54	31.10	12.55
^{14}C	5.51	6.17	21.81
^{16}O	38.01	38.43	26.27
^8Be	33.10	43.26	25.73
^{12}C	20.10	25.64	12.47
^{14}C	-0.01	1.61	19.38
^{16}O	29.60	31.48	18.29

Conclusion:

From Table-1 and Table-2 it was observed that the half-lives obtained from RMF- results are compatible with FRDM -results. Some other results are with us.

References:

[1] A. Sandulescu, D. N. Poenaru and W. Greiner, Sov. J. Part. Nucl. II 528 (1980)
[2] D.N Poenaru,et al., Phys. Rev. C 65,054308 (2002).
[3] B.D Serot and J.D. Walecka, Adv. Nucl.Phys.16:1,(1986)
[4] C. J. Horowitz, and B.D Serot, Nucl. Phys. A,368:503(1981)
[5] Swain, R.R. and Sahu B.B., Chinese Physics C, 43, 104103. (2019)
[6] G. Royer*J. Phys. G: Nucl. Part. Phys.* **26** 1149 (2000)
[7] Rashmirekha Swain et al 2018 Chinese Phys. C 42 084102.
[8] P. Moller, et al., At. Data and Nucl. Data Tables **66** (1997) 131.