Cluster decay of Ra isotope

R.R.Swain[1],* B.B.Sahu[2]
[1]Department of Physics, School of Applied Sciences,
Kalinga Institute of Industrial Technology (KIIT) University, Bhubaneswar-751024, INDIA
. * email: bbsnou@gmail.com

Introduction

When a charged particle heavier than α-particle but lighter than a fission fragment is emitted by an unstable nucleus, the process is called cluster radioactivity or heavy-ion radioactivity [1]. The cluster decay of nucleon from medium heavy nuclei was suggested by Sandulesce *et.al.* theoretically [2]. The spontaneous emission of C^{14} from Ra^{223} was first observed by Rose et al. experimentally [3]. After this first experimental confirmation, various number of experiments have been done [4-7]. It is found that half-life is not only sensitive to the orbital angular momentum L but compatible with the Q value. In our present calculation, here we are using the RMF model to calculate the Q-value using NL3 force parameter set. With this Q-value we study the cluster decay half-life of Ra isotope using the Viola-Seaborg [8] and Universal formula [9].

Theoretical Formalism

The relativistic Lagrangian density for a nucleon-meson many body system is [10]

$$L = \bar{\psi}(i\partial - M)\psi + \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma - U(\sigma) - \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu}$$

$$+\frac{1}{2}m_\omega^2 \omega_\mu \omega^\mu - \frac{1}{4}R_{\mu\nu}R^{\mu\nu} + \frac{1}{2}m_\rho^2 \rho_\mu \rho^\mu - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

$$-g_\sigma \bar{\psi}\sigma\psi - g_\omega \bar{\psi}\omega\psi - g_\rho \bar{\psi}\rho\tau\psi - e\bar{\psi}A\psi$$

Here sigma meson field is denoted by σ, omega meson field by V_μ and rho meson field is denoted by ρ_μ. $\psi$are the Dirac spinors for the nucleons.m_σ,m_ρ,m_ω are the meson masses. g_σ,g_ρ,g_ω are the coupling constants. g_2, g_3 are the parameter of the non-linear potential. These equations are solved by using Dirac spinors and the boson fields in an axially deformed harmonic oscillator. The set of coupled equations is solved numerically by a self-consistent iteration method. The Q-value can be calculated from the binding energies of parent nuclei, daughter nuclei and emitted cluster nuclei i.e.

$$Q = M(A,Z) - M(A_1,Z_1) - M(A_2,Z_2)$$

Where $M(A,Z), M(A_1,Z_1), M(A_2,Z_2)$ are the atomic masses of parent, daughter and emitted cluster respectively. The possibility to have a cluster decay process is that the decay energy of the reaction (Q value) must be greater than zero. The expression for the ∝-decay and cluster decay half life from Viola-Seaborg is given by,

$$log_{10}T_{1/2}(s) = \frac{aZ-b}{\sqrt{Q_\alpha}} - (cZ+d) + h_{log}$$

$$h_{log} = 0 \text{ for Z even and N even}$$

$$= 0.772\ for\ Z\ odd\ and\ N\ even$$

$$= 1.066\ for\ Z\ even\ and\ N\ odd$$

$$= 1.114\ for\ Z\ odd\ and\ N\ odd$$

The Q value and half lives for the emission of various clusters from the $Ra^{210-218}$ isotopes are given in Table-I. The half life calculations are also done by using universal formula for the cluster decay is given as,

$$log_{10}T_{1/2}(s) = -log_{10}P - log_{10}S + [log_{10}(ln2) - log_{10}v]$$

Where v is a constant and S is the preformation probability of the cluster at the nuclear surface which depends only on the mass number of the emitted cluster.

Table - I : Cluster decay of Ra isotopes

Parent Nuclei	Binding Energy	Daughter Nuclei	Binding Energy	Emitted Cluster	Binding Energy	Q-Value (MeV)	T1/2 (V-S)	T1/2 (Univ.)	Expt.
^{210}Ra	1631.80	^{206}Rn	1608.178	^{4}He	28.14	4.512	13.126	21.94	0.55
^{210}Ra		^{202}Po	1583.827	^{8}Be	52.527	4.548	12.86	19.65	
^{210}Ra		^{198}Pb	1559.069	^{12}C	90.581	17.844	19.1	22.81	
^{210}Ra		^{194}Hg	1533.440	^{16}O	129.223	30.857	26.91	26.54	
^{212}Ra	1649.38	^{208}Rn	1625.557	^{4}He	28.14	4.313	14.605	21.88	1.04
^{212}Ra		^{204}Po	1601.141	^{8}Be	52.527	4.284	14.82	19.56	
^{212}Ra		^{200}Pb	1575.703	^{12}C	90.581	16.9	18.2	62.64	
^{212}Ra		198Pb	1559.069	^{14}C	107.275	16.96	18.26	21.97	
^{212}Ra		^{196}Hg	1549.353	^{16}O	129.223	29.192	26.21	25.8	
^{214}Ra	1665.58	^{210}Rn	1642.462	^{4}He	28.14	5.02	9.75	22.15	0.39
^{214}Ra		^{206}Po	1618.109	^{8}Be	52.527	5.054	9.55	19.86	
^{214}Ra		^{202}Pb	1592.431	^{12}C	90.581	17.43	18.72	22.69	
^{214}Ra		^{200}Pb	1575.703	^{14}C	107.275	17.396	18.68	24.14	
^{216}Ra	1677.34	^{212}Rn	1658.086	^{4}He	28.14	8.881	-5.49	25.03	-6.74
^{216}Ra		^{208}Po	1634.462	^{8}Be	52.527	9.644	7.36	21.67	
^{216}Ra		^{204}Pb	1608.662	^{12}C	90.581	21.898	22.27	60.50	
^{216}Ra		^{202}Pb	1592.431	^{14}C	107.275	22.361	22.58	23.74	
^{218}Ra	1688.11	^{214}Rn	1668.612	^{4}He	28.14	8.636	-4.84	23.58	-4.59
^{218}Ra		^{210}Po	1649.383	^{8}Be	52.527	13.794	14.62	24.36	
^{218}Ra		^{206}Pb	1624.346	^{12}C	90.581	26.811	25.11	27.09	
^{218}Ra		^{204}Pb	1608.662	^{14}C	107.275	27.821	25.59	26.33	
^{218}Ra		^{200}Hg	1580.218	^{18}O	142.586	34.688	28.33	28.6	

Discussion

From the table it is observed that the Q value obtained from RMF results is more compatible with experimental value as we move towards the drip line nuclei and hence the half-life.

Acknowledgments

This work is supported by SERB, DST, Govt. of India, vi-de Grant No-SR/FTP/PS-106/2013.

References

1. Sushil Kumar et al J. Phys. G: Nucl. Part. Phys. **36** 015110 (2009).
2. A. Sandulescu, D. N. Poenaru, and W. Greiner, Sov. J. Part.Nucl. **11**, 528 (1980)
3. H. J. Rose and G. A. Jones, Nature (London) **307**, 245 (1984).
4. D.V. Alexandrov*et al.*, Zh.Eksp. Teor.Fiz. **40**, 909 (1984) [Sov. Phys. JETP Lett. **40**, 152 (1984)].
5. P. B. Price *et al.*, Phys. Rev. Lett. **54**, 297 (1985).
6. S. W. Barwick*et al.*, Phys. Rev. C **31**, 1984 (1985).
7. P. B. Price, Nucl. Phys. A**502**, 41c (1989).
8. V. E. Viola, Jr. and G. T. Seaborg, J. Inorg. Nucl. Chem. **28,** 741 (1966)
9. D.N. Poenaru, R.A. Gherghescu, W. Greiner, Phys. Rev. C **83**, 014601 (2011)
10. Boguta and A.R Bodmer, Nucl. Phys. A **292**, 413 (1977).