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Research Article

PROTON RADIOACTIVITY OF TANTALUM

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ABSTRACT

Using different models such as Coulomb and proximity potential model, effective liquid drop model and modified generalised liquid drop model, we have studied all possible one proton radioactivity tantalum. The calculated half-lives from the present work are compared with the available experiments. One proton decay energy is studied using recent mass excess values [Chinese Physics C Vol. 45, No. 3 (2021) 030003]. The angular momentum dependence of potential have been considered. The penetration probability (P) is studied using WKB integral. The decay constant (λ) and half-lives ($T_{1/2}$) of $^{151-157}$Ta were predicted. The identified one proton radioactivity of $^{151-157}$Ta along with half-lives and decay energies plays an important role in the future experiments. Present work may find useful applications in radiotherapy and diagnosis.

Keywords: Proton decay, Half-lives, Penetration probability, Decay constant.

1. INTRODUCTION

Proton decay is one of the key predictions of the various grand unified theories (GUTS) proposed in the1970s, another major one being the existence of magnetic monopoles. Both concepts have been the focus of major experimental physics efforts since the early 1980s. The proton decay hypothesis was first formulated by Andrei Sakharov in 1967 [1]. During the year 1981 at GSI Darmstadt one proton(1P) ground decay was observed [2]. Half-lives of proton emission of nuclei such as ^{151}Lu, ^{53}Co and so on have been studied [3, 4]. A many theoretical models [5-9] have been made used to study 1P-decay. M.Pfutzner et al., [10] observed the decays of fine ^{45}Fe atoms at the fragment separator of GSI. Bajc et al., [11] systematically studied proton decay in the minimal super symmetric SU(5) grand unified theory. Goldman and Ross [12] predicted theoretical upper limit for proton decay. Two proton decay of ^{67}Kr is experimentally observed [13]. The life time of proton has been identified by earlier researchers [14]. Santosh & Indu sukumaran [15] theoretically predicted half-lives of proton emitters with the atomic number of Z>50. The proton radioactivity has been studied using various proximity potentials [16]. Experimental evidence shows proton drip line of ^{45}Fe [17]. After bombardment of ^{92}Mo target nuclei with ^{50}C, Woods et al. [18] observed proton decay [18]. Developmental theories of proton decay has been predicted by Maglione et al., [19]. Detail analysis of proton decay has been by Rykaczewskia et al., [20]. Ferreira et al., [21] based on relativistic density functional theory, the proton radioactivity from spherical nuclei were studied.

Delion et al., [22] examined the characteristics of nuclear matter by reviewing proton emission hypotheses. Recent literature [23-25] also predicts proton emitters in the atomic number range 72<Z<88 and actinides. Many theoretical studies shows the prediction of possible decay mode in the superheavy region [26-38]. Hence, in the present work we made an attempt to study one proton radioactivity of Tantalum using different models such as Coulomb and proximity potential model (CPPM), effective liquid drop model (ELDM) and modified generalised liquid drop model (GLDM).

2. THEORETICAL FRAMEWORK

2.1. Proton emission half-lives

2.1.1. 1P-decay using Coulomb and proximity potential model (CPPM)

The one proton decay is expressed as;

$$ {}_{Z}^{A}(X)_{N} \rightarrow {}_{Z-1}^{A-1}(Y)_{N} + {}_{1}^{1}(H) + Q_{P} \tag{1} $$

where Q_P is the amount of energy released during 1P decay. The decay constant and half-lives are defined as

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\nu P P_0} \quad (2)$$

where ν is the assault frequency [39], P is the probability of penetration barrier and P_0 is the preformation probability. In the present work we have selected P_0=1 for one proton decay. The penetration probability using WKB approximation [40] is given by;

$$P = \exp\left[-\frac{2}{\hbar}\int_{Rin}^{Rout}\sqrt{2\mu(V - Q_P)}dr\right] \quad (3)$$

where μ is reduced mass, R_{in} and R_{out} are the inner and outer turning points. The inner turning point R_{in} is expressed as;

$$R_{in} = r_0(A_1^{1/3} + A_2^{1/3}) \quad (4)$$

where A_1=1 and A_2=A-1 for proton emission. R_{out} is determined by the condition $V = Q$. The r_0 is the effective nuclear constant. The total potential is evaluated as explained in [25].

2.1.2. 1P-decay using Effective liquid drop model (ELDM)

$$V_C = \frac{8\pi}{9}a^5\varepsilon\left(\theta_{2p,}\theta_D\right)\rho_c \quad (5)$$

where ρ_c is the initial charge density, $\varepsilon(\theta_{2p}, \theta_D)$ is a function of the angular variables, and a is the radius of the sharp neck. The surface potential energy is expressed as;

$$V_s = \sigma_{eff}\left(S_{2P} + S_D\right) \quad (6)$$

The term effective surface tension σ_{eff} is expressed as;

$$\frac{3}{5}e^2\left[\frac{Z_P^2}{R_p} - \frac{Z_{1p}^2}{\bar{R}_{2P}^2} - \frac{Z_D^2}{R_D}\right] + 4\pi\sigma_{eff}\left(R_p^2 - \bar{R}_{1p}^2 - \bar{R}_D^2\right) = Q \quad (7)$$

Where Z_p is the atomic number of parent nuclei, Z_{1p} is the atomic number of emitted proton and Z_D is the atomic number of daughter nuclei and other notations are as usual explained in reference [33]. The effect of the centrifugal potential energy is defined as;

$$V_\ell = \frac{\ell(\ell+1)\hbar^2}{2\mu\zeta^2} \quad (8)$$

Here μ represents the reduced mass of the system. Therefore, the effective total potential energy is constructed as;

$$V = V_C + V_s + V_\ell \quad (9)$$

The penetrability factor G is evaluated as explained in reference [33].

2.1.3. 1P-decay using Modified generalised liquid drop model (MGLDM)

The total energy of the system is given by;

$$E = E_V + E_S + E_C + E_{Prox} + E_l \quad (10)$$

The total potential is evaluated is evaluated as explained in reference [33]

The barrier penetration probability is expressed as;

$$P = \exp[-\frac{2}{\hbar}\int_{R_{in}}^{R_{out}}\sqrt{2B(r)(E(r) - E(sphere))}] \quad (11)$$

Where $R_{in} = R_d + R_\alpha$ and $B(r) = \mu$ is the reduced mass and $R_{out} = e^2 Z_d Z_\alpha / Q_\alpha$. The decay half-life is defined as;

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\nu_0 P} \quad (12)$$

here ν_0 is the assault frequency and whose value is 10^{20} S^{-1} and P is the barrier penetration probability.

3. RESULTS AND DISCUSSIONS

Using three models such as CPPM, ELDM and MGLDM, we have studied proton decay from the proton rich emitter Tantalum. The 1P-decay is energetically possible only when Q-value of the reaction is positive. The decay energy is evaluated using the following equation;

$$Q = \delta M_p - \left(\delta M_d + \delta M_z\right) + k\left(Z_P^\varepsilon - Z_d^\varepsilon\right) \quad (13)$$

where δM_P is the mass excess of the parent nuclei, δM_d is the mass excess of the daughter nuclei and δM_z is the mass excess of the emitted proton. The term $kZ_{p(d)}^\varepsilon$ is the total binding energy of electrons in the parent or daughter nuclei. The value of k =13.6 eV and ε =2.408 for the nuclei Z≤60 and k =8.7eV and ε =2.517 for the nuclei Z>60 [25]. The recent mass excess values are taken from the reference [42]. Fig. 1 shows a plot of Q-values during 1P-decay with the mass number of parent nuclei. The minimum Q-value is observed in case of ^{157}Ta with 0.941MeV and maximum is observed for ^{151}Ta with 2.361MeV when compared to their neighboring one.

Then, we have calculated total potential using three models in nuclei $^{151-157}$Ta, the studied potential as function of separation distance is shown in Fig. 2. From the Fig., the minimum potential is observed when the separation energy is 6.5fm. Then the potential gradually increases and area below the curve gives information on penetration probability.

Later, the evaluated penetration probability and 1P-decay half-lives in $^{151-157}$Ta using three models and were tabulated in table 1. The evaluated $\log T_{1/2}$ value varies between -11.21s to -0.35s in case of CPPM. However, in case of ELDM it varies between -10.55s to -0.58s and in case of MGLDM the $\log T_{1/2}$ varies between -10.18s to -0.51s for the nuclei $^{151-157}$Ta. The values obtained using present work is compared with the available experimental value [43]. The studied $\log T_{1/2}$ corresponding to $^{155-157}$Ta shows close agreement with the available experimental values. However, the value obtained using MGLDM produces experimental half-lives more accurately.

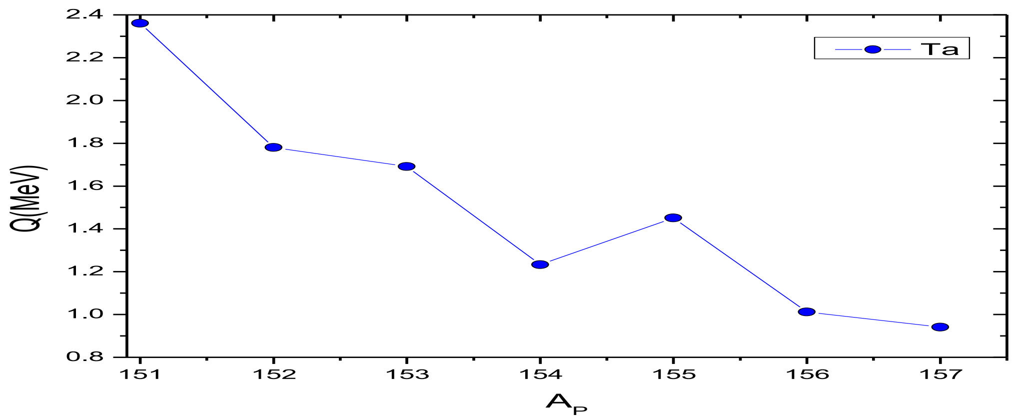

Fig. 1: A plot of Q-values during 1P- decay with the mass number of parent nuclei for the $^{151-157}$Ta nuclei

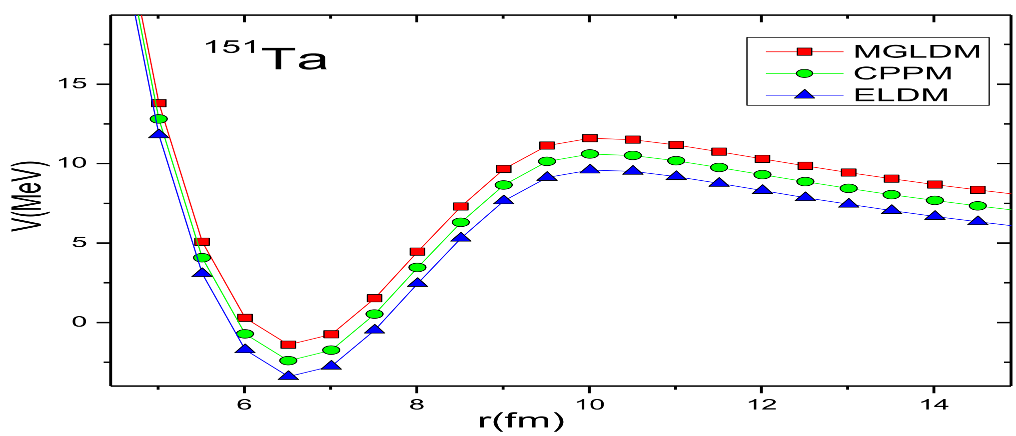

Fig. 2: Variation of total potential using three models such as CPPM, ELDM and MGLDM as function of separation distance in ^{151}Ta nuclei

Table 1: Tabulation of $\log T_{1/2}$ using three different models such as CPPM, ELDM and MGLDM for predicted proton emitters from $^{151-157}$Ta is compared to available experiments.

Parent nuclei	Daughter nuclei	Q(MeV)	ℓ	$\log T_{1/2}$			
				Expt [43]	CPPM	ELDM	MGLDM
^{151}Ta	^{150}Hf	2.361	5	-	-11.21	-10.55	-10.18
^{152}Ta	^{151}Hf	1.781	5	-	-8.67	-7.46	-7.9
^{153}Ta	^{152}Hf	1.691	5	-	-5.6	-5.84	-7.43
^{154}Ta	^{153}Hf	1.233	5	-	-5.28	-4.03	-4.1
^{155}Ta	^{154}Hf	1.451	5	-2.49	-2.68	-2.12	-2.51
^{156}Ta	^{155}Hf	1.012	2	-0.83	-0.55	-0.5	-0.85
^{157}Ta	^{156}Hf	0.941	0	-0.53	-0.35	-0.58	-0.51

4. CONCLUSIONS

Using three different models 1P-radioactivity tantalum is studied. The calculated half-lives from the present work are compared with the available experiments. The decay energy is feasible for the nuclei $^{151-157}$Ta. The angular momentum corresponding to these isotopes varies between 0 to 5$\hbar$. The evaluated logarithmic half-life value varies between -11.21s to -0.35s in case of CPPM, in case of ELDM it varies between -10.55s to -0.58s and in MGLDM the logarithmic half-lives varies between -10.18s to -0.51s for the nuclei $^{151-157}$Ta. The identified 1P-radioactivity of $^{151-157}$Ta along with half-lives and decay energies plays an important role in the future experiments. The identified proton emitters with typical half-lives and decay energies may find useful applications in radiotherapy and diagnosis.

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