Alpha decay from ground and isomeric states of $^{191-202}$At isotopes

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Introduction

Alpha decay is a fundamental decay mode of radioactive nuclei from which we can analyze the nuclear structural properties like ground state energy, half-life, nuclear clustering, shell effects, deformation of the nucleus, nuclear interaction, spin and parity, etc. Alpha decay often takes place in heavy, superheavy, and neutron-deficient nuclei with a relatively high protons-to-neutron ratio. The quantum tunneling picture to alpha decay [1, 2] leads to the development of different models [3-5] to explain the decay properties. Also, several empirical formulae [6, 7] have been proposed by different authors to determine the half-lives comparable with experimental data. It is important to study the ground state and the isomeric state decays since the studies [8] indicate the relevance of isomeric states in some cases having a lifetime greater than its ground states.

The Modified Generalized Liquid Drop Model (MGLDM) [9] developed by Santhosh et al. is an improved version of GLDM [4] and the model could explain cluster decay, α-decay, and 2α-decay in heavy and superheavy regions.

In this work, we are studying the possibility of alpha emissions from the ground and isomeric states of $^{191-202}$At isotopes using MGLDM.

Modified Generalized Liquid Drop Model (MGLDM)

In MGLDM, the macroscopic energy for a deformed nucleus is defined as,

$$E = E_V + E_S + E_C + E_R + E_P \quad (1)$$

Here the terms E_V, E_S, E_C, E_R and E_P represent the volume, surface, Coulomb, rotational, and proximity energy terms respectively.

The proximity energy term proposed by Blocki [10] et al. given as.

$$E_P(z) = 4\pi\gamma \left[\frac{C_1C_2}{C_1+C_2}\right] \Phi\left(\frac{z}{b}\right) \quad (2)$$

The barrier penetrability P is calculated by using the integral [11],

$$P = e^{\left(-\frac{2}{\hbar}\int_{R_{in}}^{R_{out}} \sqrt{2B(r)[E(r)-E(sphere)]}dr\right)} \quad (3)$$

Here, $R_{in} = R_1+R_2$, $B(r) = \mu$, and $R_{out} = \frac{e^2 Z_1 Z_2}{Q}$. R_1 and R_2 are the radius of the daughter nuclei and emitted cluster respectively, and μ the reduced mass and Q is the released energy.

The partial half-life is related to the decay constant λ by

$$T_{1/2} = \left(\frac{ln\,2}{\lambda}\right) = \left(\frac{ln\,2}{\nu P_\alpha P}\right) \quad (4)$$

The assault frequency ν has been taken as 10^{20} s^{-1} and P_α, the alpha preformation factor is taken as 1.

Results and discussion

The alpha decay is possible only when the Q value,

$$Q = \Delta m_p - (\Delta m_\alpha + \Delta m_d) \quad (5)$$

is +ve. Here $\Delta m_p, \Delta m_\alpha, \Delta m_d$ are the mass excess of parent, cluster, and daughter nuclei, respectively. The first three columns of Table 1 indicate the parent and daughter nuclei and the corresponding Q-values [12] of astatine isotopes in the mass number range 191 to 202. Also, the Q values of the isomeric states decay (from the jth excited state of the parent to the ith excited state of the daughter) are calculated by using the equation,

$$Q_{j\to i} = Q_{g.s\to g.s} + E_{jp} - E_{id} \quad (6)$$

Where, E_{jp} and E_{id} are the excitation energies [13] corresponding to parent and daughter nuclei.

Here we have only considered the favored decays (ℓ=0) in which the parent and daughter nuclei have the same spin and parity.

The computed alpha decay half-lives by using MGLDM are given in the 4th column of the table, which can be compared with the 5th column, in which the experimental half-lives are included. Analyzing both columns, we can see that the predicted half-lives are very close to the experimental results. To measure the dependability of our model, we have measured the standard deviation by using the formula,

$$\sigma = \sqrt{\frac{1}{n}\sum(log_{10}T_{1/2}^{exp.} - log_{10}T_{1/2}^{calc.})^2} \quad (7)$$

And the average deviation can be measured as,

$$\bar{\sigma} = \frac{1}{n}\sum|log_{10}T_{1/2}^{exp.} - log_{10}T_{1/2}^{calc.}| \quad (8)$$

The standard deviation and average deviation of the computed values are evaluated as 0.29 and 0.25, respectively, which shows the reliability of our model. Also, graphical explanations of the data are always a better way of understanding mathematical expressions. Here, our results are represented graphically in Fig. 1, in which the Geiger-Nuttall plot [14] (left panel) relates the logarithmic predicted half-lives with $Q^{-1/2}$ is given. It is a straight line and can be represented as

$$\log_{10}T_{1/2} = 132.33\ Q^{-1/2} - 49.84 \quad (9)$$

Also, the second portion of Fig. 1 denotes Brown's law [15], which connects $\log_{10}T_{1/2}(s)$ with $Z_d^{0.6}Q^{-1/2}$. This plot is also a straight line and can be expressed as,

$$\log_{10}T_{1/2} = 9.34\ Z_d^{0.6}Q^{-1/2} - 49.84 \quad (10)$$

These two curves, showing all the computed values lie on a single straight line, increase the reliability of our model.

Our investigation of the ground and isomeric state alpha decays of $^{191-202}$At will serve to guide future experiments.

Table 1 The Q value, experimental and computed half-lives for alpha decay from $^{191-202}$At isotopes.

Parent Nuclei	Daughter Nuclei	Q value (MeV)	$\log_{10}T_{1/2}(s)$	
			Exp.	Calc.
^{191}At	^{187}Bi^{m1}	7.71	-2.77	-2.19
^{191}At^{m1}	^{187}Bi^{m2}	7.82	-2.67	-2.52
^{192}At^{m1}	^{188}Bi^{m1}	7.59	-1.69	-1.82
^{192}At^{m2}	^{188}Bi^{m2}	7.38	-0.97	-1.09
^{193}At	^{189}Bi^{m1}	7.39	-1.55	-1.15
^{193}At^{m1}	^{189}Bi^{m2}	7.48	-1.67	-1.46
^{193}At^{m1}	^{189}Bi^{m3}	7.26	-0.95	-0.68
^{194}At^{m1}	^{190}Bi^{m1}	7.34	-0.52	-1.00
^{194}At^{m2}	^{190}Bi^{m1}	7.33	-0.40	-0.96
^{195}At	^{191}Bi^{m1}	7.10	-0.48	-0.16
^{195}At^{m1}	^{191}Bi^{m2}	7.22	-0.81	-0.61
^{197}At	^{193}Bi	7.10	-0.46	-0.21
^{197}At^{m1}	^{193}Bi^{m1}	6.85	0.57	0.75
^{198}At	^{194}Bi	6.89	0.67	0.54
^{198}At^{m1}	^{194}Bi^{m1}	7.00	0.08	0.15
^{200}At	^{196}Bi	6.60	1.92	1.67
^{200}At^{m1}	^{196}Bi^{m1}	6.54	2.04	1.89
^{200}At^{m2}	^{196}Bi^{m2}	6.68	1.84	1.35
^{202}At	^{198}Bi	6.35	2.70	2.66
^{202}At^{m1}	^{198}Bi^{m1}	6.26	3.32	3.08
^{202}At^{m2}	^{198}Bi^{m2}	6.35	2.68	2.66

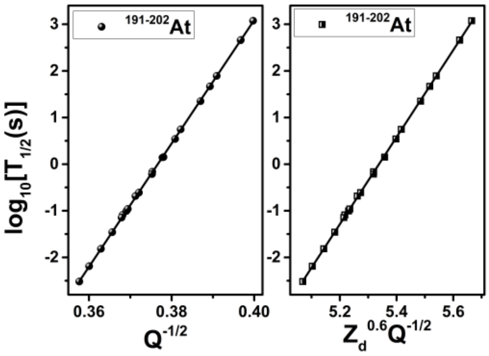

Fig. 1 Geiger-Nuttall plot and Brown law for alpha decays for $^{191-202}$At isotopes.

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