Alpha decay from the ground states of $^{169\text{-}190}$Au isotopes

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Introduction

Current research in nuclear physics is exciting in the context of α-decay, as it offers a pathway to reach heavy and superheavy (might be unknown) nuclei through α-decay chains that lead to known nuclei. These studies provide reliable information about structural properties, such as half-lives, shell effects, deformation, etc. Researchers have developed numerous theoretical models and empirical formulae to explore the likelihood of alpha decay.

In this study, we investigate the possibility of alpha emissions from the ground states of the Au isotopes using modified Generalized Liquid Drop Model (MGLDM) [1], developed by Santhosh et al., and compare it with experimental values. Additionally, we improve the semFISS formula [2], including the angular momentum contribution, and the half-lives are calculated and compared.

Modified Generalized Liquid Drop Model (MGLDM)

The macroscopic energy for a deformed nucleus,

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

Here, the volume, surface, Coulomb, and rotational energy terms are represented as E_V, E_S, E_C, and E_R, respectively. E_P is the proximity energy term proposed by Blocki [3] et al.

The barrier penetrability P is calculated by using the integral,

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

Here, $R_{in} = R_1+R_2$, $B(r) = \mu$, and $R_{out} = \frac{e^2Z_1Z_2}{Q}$. $R_1\ and\ R_2$ are the radius of the daughter nuclei and alpha particle respectively, μ is the reduced mass and Q is the released energy.

The relation connecting the partial half-life with the decay constant λ, preformation factor P_α, and the assault frequency ν is given by,

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\nu P_\alpha P} \quad (3)$$

Improved SemFISS Formula (ISFF)

The semi-empirical formula [2] based on fission theory is improved by considering the angular momentum factors and the revised formula is,

$$log_{10} T_{1/2}\,(s) = 0.43429K_s\chi + \frac{a\ell(\ell+1)}{\sqrt{A_dZ_dA^{-2/3}}} + b \quad (4)$$

with a = 2.092911 and b = -19.378485.

K_s is the WKB penetrability term corresponding to the separated fragments,

$$K_s = 2.52956Z_d(A_d/AQ)^{1/2} \times [arccos\sqrt{x} - \sqrt{x(1-x)} \quad (5)$$

where, $x = 0.4253Q(A_\alpha^{1/3} + A_d^{1/3})/Z_d$

$$\chi = B_1 + B_2y + B_3z + B_4y^2 + B_5yz + B_6z^2 \quad (6)$$

Here, the Bk values are taken from Ref. [4], and y and z are the relative distances of the number of neutrons and protons from the respective closest magic-plus-one numbers.

Results and discussion

We have considered the isotopes of Au in the range 169≤A≤190 giving the alpha radioactivity and transforming into the daughter nuclei $^{165\text{-}186}$Ir. The disintegration energy can be abbreviated as Q-value which can be taken from the Ref. [5].

We employed the Modified Generalized Liquid Drop Model (MGLDM) with a chance of preformation for each alpha particle before the penetration (Pα) [6], to calculate the half-lives of these isotopes. The half-lives calculated using MGLDM were compared with experimental results and were found to be consistent. Also, we utilized the improved semFISS formula (ISFF) to calculate the half-lives, and the results obtained were compared with MGLDM results and experimental half-lives [7]. These results reveal that the predicted half-lives are close to the experimental values.

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Table 1 Predictions of alpha decay half-lives from $^{169\text{-}190}$Au with $^{165\text{-}186}$Ir as daughter nuclei.

Parent Nuclei	**Q-value** (MeV)	**$\log_{10}[T_{1/2}(s)]$**		
		Exp.	MGLDM	ISFF
^{169}Au	7.38	-3.82	-3.10	-2.60
^{170}Au	7.17	-2.58	-2.36	-2.75
^{171}Au	7.08	-4.65	-2.17	-1.68
^{172}Au	6.92	-1.55	-1.53	-1.83
^{173}Au	6.84	-1.53	-1.35	-0.84
^{174}Au	6.69	-0.81	-0.76	-0.94
^{175}Au	6.58	-0.64	-0.45	0.05
^{176}Au	6.43	0.14	0.20	0.18
^{177}Au	6.29	0.57	0.62	1.14
^{178}Au	6.06	1.33	1.71	1.85
^{179}Au	5.98	1.51	1.92	2.46
^{180}Au	5.83	3.13	2.79	3.69
^{181}Au	5.75	2.70	2.93	3.49
^{182}Au	5.52	--	4.21	5.39
^{183}Au	5.46	3.89	4.27	4.86
^{184}Au	5.23	5.19	5.57	6.58
^{185}Au	5.18	4.99	5.68	6.37
^{186}Au	4.91	7.90	7.35	8.79
^{187}Au	4.75	--	8.43	10.13
^{188}Au	4.81	--	8.23	11.89
^{189}Au	4.33	--	11.21	12.97
^{190}Au	3.91	--	14.65	19.16

We analyzed the reproduced results and measured their standard deviations to estimate the dependability of the methods used. The standard deviations of the computed values are 0.37 and 0.81, respectively, for MGLDM and ISFF.

The results of MGLDM can easily be demonstrated graphically and the dependability of model calculations can be assured. The left panel of Figure 1 gives the Geiger-Nuttall plot (GN plot) [8], which can be represented as,

$$log_{10}T_{1/2} = 128.02Q^{-1/2} - 50.30 \qquad (7)$$

The right panel of Fig. 1 denotes the New Geiger-Nuttall law (New GN law) [9], showing separate straight lines for favored ($l = 0$) and unfavored decays ($l \neq 0$). The New G-N plot can be mathematically represented as,

$$log_{10}T_{1/2} = A(Z_d^{0.8} + l^{0.5})Q^{-1/2} + B \qquad (8)$$

Where, A=3.85 and B=-48.87 for favored cases and A=3.49 and B=-46.06 for unfavored cases. These two curves increase the reliability of our model. Our analysis of alpha decays of $^{169\text{-}190}$Au will provide valuable guidance for future experimental endeavors.

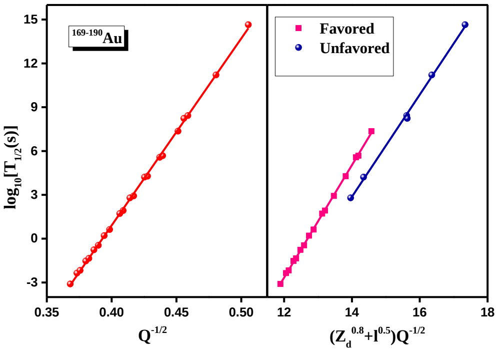

Fig. 1 Geiger-Nuttall plot and New Geiger-Nuttall plot for alpha decays for $^{169\text{-}190}$Au isotopes.

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