The α-decay half-lives of superheavy nuclei using different semi-empirical mass formulae

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Introduction

The systematic investigation of the unknown nuclei that lie far away from the line of stability has drawn the interest of researchers of nuclear physics around the globe. The α-decay energy Q_α and the corresponding half-lives are used in the investigation of superheavy nuclei(SHN), especially in neutron-rich heavy and superheavy mass regions. The SHN from Z =112-118 has been synthesized via hot and cold nuclear fusion reactions. Various theoretical and experimental efforts have been employed in the direction of the superheavy mass region beyond Z = 114 nuclei having a long α-decay half-life [1]. In the present study, the α-decay half-lives of SHN Z = 114 ranging from A = 284 to 292 have been studied by employing different semi-empirical formulae namely, the modified the universal decay law (MUDL), Modified Brown formula (MB), universal decay law (UDL), the universal decay law (isospin effect), and compared with the experimental results. The study of these isotopes may be helpful in upcoming experiments on the superheavy mass region.

Theoretical Formalism

The relativistic mean-field (RMF) formalism has been generally used to describe the properties of finite nuclei and infinite nuclear matter along with the drip-line region. In RMF, the nucleus is assumed as a combined system of nucleons interacting via the exchange of photons and mesons. A detailed analysis of the RMF can be found in Ref. [2] and references therein. The relativistic Lagrangian density provides the phenomenological description for a nucleon-meson many-body system is as follows:

$$\begin{aligned}\mathcal{L} &= \overline{\psi}\{i\gamma^\mu\partial_\mu - M\}\psi + \frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma \\ &-\frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi}\psi\sigma \\ &-\frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_w^2\omega^\mu\omega_\mu - g_w\overline{\psi}\gamma^\mu\psi\omega_\mu \\ &-\frac{1}{4}\vec{B}^{\mu\nu}.\vec{B}_{\mu\nu} + \frac{1}{2}m_\rho^2\vec{\rho}^\mu.\vec{\rho}_\mu - g_\rho\overline{\psi}\gamma^\mu\vec{\tau}\psi\cdot\vec{\rho}^\mu \\ &-\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\overline{\psi}\gamma^\mu\frac{(1-\tau_3)}{2}\psi A_\mu. \qquad (1)\end{aligned}$$

Here ψ represents the Dirac spinors of the nucleons. and $g_\sigma(m_\sigma)$, $g_\rho(m_\rho)$, and $g_\omega(m_\omega)$ are the coupling constants (masses) for σ, ρ, and ω mesons, respectively. τ and τ_3 represents the isospin and third component of isospin. The constants $e^2/4\pi$, g_2, and g_3 are the coupling constants for self-interacting non-linear σ-meson field and photon, respectively. A_μ and M represents electromagnetic field and the nucleon mass, respectively. The vector field tensors for the ω^μ, $\vec{\rho}_\mu$ and photon fields are also briefly outlined in Ref. [2].

Result and Discussions

The alpha decay properties of SHN Z = 114 having isotopes A = 284-292 have been studied with the help of relativistic mean-field formalism for NL3* parameter set which is the modified version of the NL3 parameter set. The Q_α values have been calculated by using the non-linear NL3* parameter set

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and compared with the experimental data as shown in Fig. 1.

From the figure, the RMF formalism

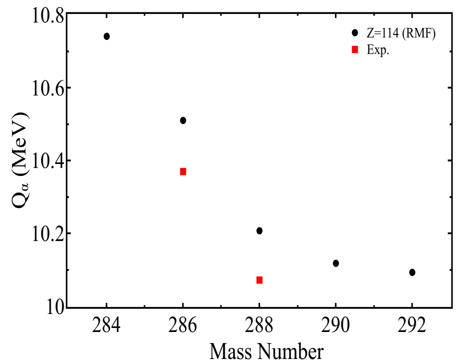

FIG. 1: The α-decay (Q_α energy) for Z = 114 nuclei using RMF (NL3*) are given along with the available experimental data [3]. See text for details.

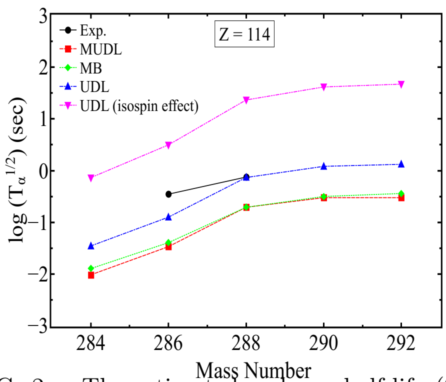

FIG. 2: The estimated α-decay half-life ($T^{\alpha}_{1/2}$) for Z = 114 nuclei using the universal decay law (UDL), the universal decay law (isospin effect) [5], modified the universal decay law (MUDL), and Modified Brown formula (MB) and compared with the experimental results [6].

is observed to slightly overestimate the experimental Q-values. These obtained RMF(NL3*) Q-values are further used in the calculation of alpha-decay half-lives of superheavy mass-region.
The alpha decay half-lives for these isotopes have been systematically analyzed by using the four different semi-empirical mass formulas namely; the universal decay law (UDL) [4], the universal decay law isospin effect) [5], modified the universal decay law (MUDL) [4], and Modified Brown formula (MB) [4] and compared these results with the experimental data wherever available [6].

It is predicted from the graph 2 that the UDL formula shows good agreement with the experimental results. On the other hand, modified the universal decay law (MUDL), and Modified Brown formula (MB) shows slightly lower values except for UDL with isotopic effect.

Thus, it is concluded from the above results that the universal decay law (UDL) is more consistent in comparison to the other semi-empirical formulas for the predictions of half-lives for the SHN.

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