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Temperature-dependent potential in alpha-decay process

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Abstract

The temperature dependence of the alpha-nucleus potential and the corresponding alpha-decay half-lives are studied with different versions of the proximity potential. The transfer matrix approach is applied to calculate the penetration probability of alpha particle. The barrier heights and widths increase with the excitation energies of the parent nuclei, which results in the increase of the alpha-decay half-lives with increasing of the temperature and decreasing of the surface energy coefficient. Based on the measured alpha-decay half-lives, we find that the temperature of the parent nuclei in decaying process decreases with the mass number of the parent nuclei.

Keywords: Half-lives; Alpha-decay; Temperature dependence; Barrier potential; Penetration probability

1. Introduction

Alpha-decay not only is one of the most important decay modes of super-heavy nuclei, but also plays a role in the study of nuclear structure of heavy nuclei [1–3]. Theoretical mechanism of alpha-decay is regarded as a quantum mechanical tunneling through the potential barrier between alpha particle and the daughter nucleus [4]. The accurate description of the potential barrier is critical in the alpha decay studies. The potential between the alpha particle and the daughter nucleus is usually described as the sum of the Coulomb, nuclear and centrifugal potential in which the accurate form of the nuclear potential is unknown. Many efforts have been

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made to study the alpha-decay half-lives by applying different models in calculation of nuclear potential in recent years [3,5–7]. One of the successful and applicable models is by using the proximity potential which is a function of separation between the surfaces of the two nuclei [8]. Many versions of proximity potential have been proposed by different groups in order to improve the models [9–12]. Recently, Salehi and Ghodsi modified the proximity potential by using temperature dependence of the surface energy coefficient [13]. Within the framework of this refined model it turned out to be possible to reproduce satisfactorily height and position of the barriers and the fusion cross sections.

In this work, we attempt to study the alpha-decay half-lives of heavy nuclei by considering the temperature dependence of the proximity potential and using transfer matrix approach [14] for calculating the penetration probability across the potential barrier. Although the traditionally WKB (Wentzel–Kramers–Brillouin) [15,16] approximation is widely used in the calculations of the penetration probability, we would like to emphasize that the transfer matrix approach is more accurate comparing with the traditional WKB method when the potential profile varies abruptly and the particle energy is close to the barrier height [14].

This paper is organized as follows. In Section 2, the modified proximity potential with temperature dependence and the transfer matrix approach for calculation of the penetration probability are introduced. In Section 3 we present the results and discussions. The summary and some concluding remarks are given in Section 4.

2. Theoretical formalism

The proximity potential method has been extensively used in the relevant literature for describing the alpha-decay [7,12,17,14]. Here, we just briefly review the basic relations that used in this paper. The interaction potential between the alpha particle and the daughter nucleus where the total potential is expressed as the sum of the nuclear potential, the Coulomb potential and the centrifugal potential,

$$E(R) = V_N(R) + V_C(R) + \hbar^2 l(l+1)/\big(2\mu R^2\big). \tag{1}$$

Where μ is the reduced mass. The Coulomb interaction potential is given by,

$$V_c(R) = \begin{cases} Z_\alpha Z_d e^2/R & : R > R_c \\ (Z_\alpha Z_d e^2/2R)[3-(R/R_c)^2] & : R \le R_c \end{cases} \tag{2}$$

with $R_c = 1.24\ (R_\alpha + R_d)$. R_α and R_d denote the charge radii of α-particle and the daughter nuclei, respectively. In this work $V_N(R)$ is described by [8],

$$V_N(r) = 4\pi\gamma b\overline{R}\Phi(\xi) \tag{3}$$

where $\xi = s/b$ and $s = r - R_1 - R_2$. $\Phi(\xi)$ is the universal function that was defined as follows,

$$\Phi(\xi) = \begin{cases} -\frac{1}{2}(\xi-2.54)^2 - 0.0852(\xi-2.54)^3 & : \xi \le 1.2511 \\ -3.437e^{-\xi/0.75} & : \xi > 1.2511 \end{cases} \tag{4}$$

$\overline{R} = \frac{C_1 C_2}{C_1+C_2}$ is the reduced radius with Sussmann's radius $C_{1,2}$ of the spherical projectile (target) nucleus,

$$C_i = R_i\left[1-\left(\frac{b}{R_i}\right)^2\right]. \tag{5}$$

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