Available online at www.sciencedirect.com
SCIENCE DIRECT®

Nuclear Physics A 753 (2005) 174–185

NUCLEAR PHYSICS A

Systematical calculation of α decay half-lives by density-dependent cluster model

Chang Xu [a,*], Zhongzhou Ren [a,b]

[a] *Department of Physics, Nanjing University, Nanjing 210008, China*
[b] *Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

Received 11 October 2004; received in revised form 25 January 2005; accepted 24 February 2005

Abstract

Systematical calculations on the α decay half-lives of nuclei are carried out in a new cluster model (density-dependent cluster model) where the effective potential between α cluster and daughter nucleus is obtained from the double folded integral of the renormalized M3Y nucleon–nucleon interaction with the density distributions of the α particle and the daughter nucleus. The model reproduces the experimental half-lives within a factor of 3 for many nuclei. The model also works well for new superheavy elements which are the current interests of nuclear physics and chemistry. This successful description of α decay data is due to the correct incorporation of the low-density behavior of the effective nucleon–nucleon interaction in the popular M3Y potential. The effective α-core potential of the density-dependent cluster model is analyzed and discussed.

PACS: 23.60.+e; 21.10.-k; 21.60.-n

Keywords: α decay; Density-dependent cluster model; Half-lives

* Corresponding author.
E-mail addresses: changxu99@hotmail.com (C. Xu), zren@nju.edu.cn (Z. Ren).

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2005.02.125

1. Introduction

The α decay of nuclei plays an important role for the development of both modern physics and chemistry. It was first observed by Becquerel in 1896 as an unknown radiation and further studied by M. Curie and P. Curie [1]. M. Curie and P. Curie identified two chemical elements (polonium and radium) by their strong radioactivity [1]. In 1908 Rutherford found that this unknown radiation consists of ^{4}He nuclei and named it as the α decay for convenience [2]. In 1910s α scattering from natural radioactivity on target nuclei provided first information on the size of a nucleus and on the range of nuclear force [2]. In 1928 Gamow tried to apply quantum mechanics to α decay and explained it as a quantum tunneling effect [2]. This is the first quantum mechanical explanation of α decay and it proved the correctness of quantum mechanics for nuclei in the end of 1920s. A similar explanation is also given by Gurney and Condon in 1929 [2].

Experimentally α decay of nuclei is one of efficient methods to identify new chemical elements or new nuclides by the observation of α decay chain from unknown parent nucleus to a known nuclide [3,4]. Many new elements and new nuclides are identified in this way. These include many heavy elements such as those with $Z = 84$–88 and with $Z \geqslant 100$. To date α decay is still used as a reliable way to identify new superheavy elements which have been synthesized and which are being synthesized at GSI, at Berkeley, at Dubna, at RIKEN, and at GANIL.... Although α decay is very useful for experimental nuclear physics, the development on the quantitative description of α decay is slow due to the complexity of both the nuclear potential and the nuclear many-body problem.

Various theoretical approaches, both phenomenologically and microscopically, have been used to describe α correlation or α decay which include shell model, cluster model, and a mixture of shell and cluster model configurations [2,5–22]. Mang and Rasmussen reviewed the theoretical investigation of α decay [5,6] in 1960s. Brink et al. [7] calculated the properties of nuclear matter and concluded that the α clusters appear when the density of nuclear matter decreases to the $1/3$ density in the center of heavy nuclei. This suggests that the α cluster can appear at the surface of heavy nuclei [7]. Tonozuka and Arima calculated the probability of α cluster within the framework of nuclear shell model [8]. Wildermuth and Tang [9] systematically discussed the cluster structure in nuclear structure and in nuclear reactions. Horiuchi and Takemoto et al. studied α-clustering structure in nuclei and in nuclear matter [11,12]. Delion and Sandulescu [14] calculated the α decay of some deformed nuclei. Varga et al. [13] investigated the absolute α-decay width of ^{212}Po in a combined shell and cluster model. A review article on theoretical aspect of α decay is presented by Lovas et al. [21]. A recent review on experimental aspect is made by Hodgson and Běták [22].

In this paper we use a new cluster model of α decay where the effective potential between α cluster and daughter nucleus is obtained from a double folded integral of the renormalized M3Y potential with the density distributions of the α particle and daughter nucleus. The popular M3Y potential is derived by Bertsch et al. [23] where it is from the fitting of the G matrix element of the Reid potential. The parameterized form of the M3Y potential by Satchler and Love [24–26] is used for calculations of α decay in this paper.

This paper is organized in the following way. In Section 2 we present the framework of the new cluster model for α decay. The numerical results and discussions are given in