CONTRIBUTIONS OF AURELIU SĂNDULESCU TO THE THEORY OF ALPHA DECAY

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Received March 27, 2007

These notes are dedicated to my Professor A. Săndulescu who, for half a century, has been more consistent than anyone else in championing the alpha decay theory. We shortly review the essential contributions of A. Săndulescu and his collaborators to the development of theoretical and mathematical methods in the study of alpha decay and related phenomena like clustering, fine structure, collective excitations, shell effects, finite size corrections included in formation and reaction amplitudes and resonance aspects of nuclear dynamics.

1. OBJECTIVES

One of the most important objectives of nuclear theory is to use the data extracted from various nuclear reactions in order to derive conclusions concerning nuclear properties. This supposes developing and applying theories and methods of prediction, analysis and interpretation of specific data, with the aim of achieving a deeper understanding of the physical nature of quantum many-body systems. Many developments in radioactive element research allow us to formulate a consistent theory of radioactive decay. This work presents the theory extended by Săndulescu and his collaborators, from simple to more complex nuclear structures, and from the one-body to many-body (shell model) treatment of the emission rates near the resonance threshold. The references include all the formal considerations in deriving the basic formulae, as well as practical computational methods, based on self-consistent models for nuclear shell structure and resonance low-energy reaction dynamics.

2. ACHIEVEMENTS

In addition to the works described in the extended paper of Dr. Hb. S. Mișicu [1], dedicated to Professor Aurel Săndulescu's 70th anniversary, these notes include some other contributions in the field:

Rom. Journ. Phys., Vol. 52, Nos. 8–10, P. 775–778, Bucharest, 2007

1. SHELL MODEL APPROACH TO THE TRANSFER FORM FACTORS

1.1. Taylor-series methods for two and four-nucleon transfer form factors (Săndulescu, Silișteanu) [2].

A new method is developed for transforming the infinite or finite well two-nucleon wawe functions from individual coordinates to relative and c.m. coordinates by expanding two-nucleon vawe functions around the c.m. of the system. Finite size corrections to the point approximations of the two and four nucleon (alpha) transfer form factors with harmonic oscillators and Woods-Saxon single particle functions are computed and compared with the results obtained using other methods (Mang, Talmy and Moshinsky).

2. NEW RESONANCE FORMULAS FOR THE PARTICLE DECAY WIDTH

2.1. One-body theory of alpha-particle decay using the resonance states (Săndulescu, Silișteanu, Rizea) [3].

2.2. Direct determination of one-body alpha decay widths (Rizea, Săndulescu,) [4].

2.3. On potential ambiguities in alpha decay and alpha scattering (Rizea, Sandulescu, Scheid) [5].

2.4. One-body width formula equivalent to the Breit and Feshbach formulas (Silișteanu, Scheid, Săndulescu), chapter 4 in [6].

3. ALPHA DECAY WIDTHS WITH THE INTERNAL STRUCTURE OF THE ALPHA PARTICLE.

3.1. Alpha decay widths and the structure of the alpha particle (Săndulescu, Tarnoveanu, Rizea) [7].

4. UNIFIED TREATMENT OF THE ALPHA DECAY IN THE THEORY OF NUCLEAR REACTIONS

4.1. Alpha decay within Feshbach theory of nuclear reactions (Săndulescu, Silișteanu, Wuensch) [8].

In the framework of Feshbach theory of nuclear reactions the α-decay widths are determined by the α-daughter-nucleus optical potential and by the preformation factors. It is shown that the calculated absolute values of the α-widths for the light Po isotopes are in good agreement with the experimental data if the real part of the optical potential using parameters obtained by fitting low-energy α-scattering is used.

5. DECAY WIDTH ESTIMATES WITH THE SELFCONSISTENT MODELS FOR CLUSTERING AND RESONANCE SCATTERING EFFECTS

5.1. Proton, alpha and cluster emission of the proton rich nuclei with $52 < Z < 56$ and $52 < N < 60$ (Săndulescu, Silișteanu, Scheid) [6].

For studying the rates of radioactive nuclei in various decay chains we propose an approach unifying the advantages of the superfluid model for nucleon clustering and of the classical model for resonance tunneling in many-particle systems. We discuss the theoretical bases and numerical approach for decay rate predictions for some highly unstable proton rich trans-tin nuclei. Information on structure and nuclear mass of some exotic nuclei not yet experimentally accessible have also been obtained from a detailed analysis of the proton, alpha and cluster decay rates. It is shown that the Casten-type rate systematics works very well in various schemes of valence nucleon numbers revealing similar decay properties for the nuclei with the same numbers of valence protons and neutrons above the ${}^{100}_{50}\mathrm{Sn}^{50}$ and ${}^{208}_{82}\mathrm{Pb}^{126}$ magic cores.

The reliability of these new results is demonstrated by a comparison between relevant classical theories and other approaches [11, 12, 13]. Some applications, results and numerical examples are given in [14, 15]. Applications of the theory to the resonance spectroscopy with position-sensitive charge particle detectors are of great importance, since high-precision calculation of partial widths of resonances have become available and these resonances are first observed in experiments. Professor A. Săndulescu has effectively contributed to the formulation of a quantitative theory of radioactive decay, within single channel and multichannel resonance scattering approaches, and also to the interpretation of alpha decay data obtained in the past by means of natural radioactive sources and nowdays by means of reactions with accelerated heavy ions.

3. PERSPECTIVES

Recent significant progress in the superheavy element (SHE) research has delivered challenging experimental alpha data. The new data may be used in determination of a nuclide's "existence" or particle (cluster) stability, its main decay modes and half-life, its ground state mass, or its excited states and their decay. The measurements of α-decay may provide a powerful method to extend the energy and spin-parity informations from daughter to parent nuclei with support from theoretical investigations and this may lead to identification of nuclei in long decay chains and determining the excitation energies of the daughter nucleus from decay and in-beam studies. Thus, we can see that after a century, alpha decay continues to give us unique information on the nuclear-scale structure of the radioactive elements.

Acknowledgements. The author would like to express his gratitude to Dr. M. Rizea, Dr. S. Mişicu, Dd. A. Şandru and A. Neacşu for providing valuable information on Prof. A. Săndulescu's scientific curriculum.

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