AURELIU SĂNDULESCU, A LIFE DEDICATED TO THE NUCLEAR PHYSICS:
From α-decay theory to magic radioactivity and superheavy nuclei

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The first paper in theoretical nuclear physics, written by G. Gamow [1], explained the Geiger-Nuttall law, connecting the α-decay width to the Q-value, in terms of the α-particle penetration through the Coulomb barrier. Thirty years later, the R-matrix theory [2] made a step forward with respect to the Gamow picture, by expressing the decay width as a product between the barrier penetrability and the α-particle formation probability. At that time it was not possible to estimate this quantity. The formation probability should take into account the nuclear structure details, by expressing the cluster wave function in terms of two proton and two neutron nuclear orbitals. Only in sixties it became possible to figure out a procedure to accomplish this task. Prof. Aureliu Săndulescu proposed a method to do this in a paper submitted to Nuclear Physics in 1960, but published only in 1962 [3]. It was based on the Talmi-Moshinsky procedure, recoupling the coordinates of two particles to the center of mass and relative motion. This method is different from another approach proposed almost simultaneously by H.J. Mang [4].

In this way, it became possible to describe microscopically the process of the α-particle formation on the nuclear surface, as a resonant state. Unfortunately, the computing possibilities allowed to consider only few single particle orbitals and therefore the decay width was underestimated by five orders of magnitude. Only in nineties it became possible to include up to 18 major shells in the single particle basis diagonalizing the mean field [5], but still the absolute decay width remained underestimated by two orders of magnitude. Later on, it was realized that the microscopic formation probability is not consistent with the external Coulomb wave [6]. Thus, the internal logarithmic derivative is almost constant along an isotope chain, at variance with the similar quantity given by the external Coulomb function, strongly depending on the Q-value. It was prof. Aureliu Săndulescu idea to predict Q-values, and therefore the binding energies, by using the logarithmic derivative of the microscopic formation amplitude. In principle this is possible only by including a cluster component in addition to the formation amplitude [7], according to an older idea evidenced in Ref. [8].

Thirty five years ago, prof. Aureliu Săndulescu intuition contradicted the general opinion that "in nuclear physics everything was discovered", by predicting a new type of radioactivity. Nowadays, it is widely recognized that the theoretical prediction of spontaneous heavy cluster emission in 1977 [9, 10] and later in Ref. [11] was an outstanding achievement, comparable to the discovery of α, β and γ types of radioactivity in 1896 by Henri Becquerel, awarded by the Nobel prize in 1903. Its theoretical prediction was based on the discovery of the so-called cold valleys in the potential energy of those binary partitions containing a partner close to the double magic nucleus ^{208}Pb, similar to the already known α-particle valleys. It was predicted only one event for ^{14}C emission, compared with 10^{10} α-decays.

This new type of radioactivity was experimentally detected in 1984 by H.J. Rose and G.A. Jones, at the Oxford University [12]. The experiment was independently confirmed [13]. In 1985 the spontaneous emission of a heavier cluster, namely ^{24}Ne from ^{231}Pa, ^{233}U and ^{230}Th, was detected by prof. Aureliu Săndulescu and prof. S.P. Tretyakova in Dubna [14, 15]. The results were very soon confirmed by prof. B. Price and coworkers in Berkeley [16]. In the years after these major developments the experimental techniques were improved. Thus, there were detected clusters like oxygen, magnesium or silicon [17]. The largest known half-life in heavy cluster radioactivity is 10^{29} seconds for the neon emission.

Prof. Aureliu Săndulescu generalized the quantum mechanics to the dynamics of open systems, describing as particular cases radioactive processes, in the already well known reference [18]. Recently, microscopic calculations within the Two Center Shell Model confirmed his idea, namely it was evidenced a ”cold fission” path in the emission of ^{14}C [19], different from the standard fission valley.

Heavy cluster emission is an intermediate decay mode between α-decay and fission. It is mentioned, together with the reference [11] in **The New Enciclopaedia Britannica**, 15$^{\text{th}}$ edition vol. 14, p. 371, (Enciclopaedia Britannica, Inc. 1998) as the fourth kind of radioactivity, together with α, β and γ decays. It also was introduced in the Physics and Astronomy Classification Scheme (PACS): **23.70.+j Heavy-particle decay**.

The investigation of cold valleys for various binary combinations by prof. Aureliu Săndulescu lead in the same period to a new important discovery, namely the production of superheavy nuclei [20]. The main idea was to overcome the quasifission phenomenon, hindering the possibility to obtain superheavy elements, by using the cold fragmentation valleys in the potential energy surface between different combinations giving the same compound nucleus. Later on in the reference [21] it was shown that the most favorable combinations with $Z \geq 104$ are connected with the so-called Pb potential valley, *i.e.* the same valley of the heavy cluster emission. In this way it was possible to synthesize in Darmstadt nuclei with $Z \leq 112$ [22].

The fragmentation valley corresponding to the double magic nucleus ^{48}Ca can be used in order to reach the region beyond $Z \geq 114$. Due to its double magicity and a large number of neutrons, it became possible to search for new superheavy elements by using ^{48}Ca [22–24] as a projectile on various transuranium targets. Nowadays it is worldwide recognized that the production of many superheavy elements with $Z \leq 118$ in Dubna during last three decades was based on this proposal [22, 25].

These are among the most important achievements of the Romanian physics, due to Acad. Aureliu Săndulescu, celebrating this year his 80th anniversary.

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