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The 2012 Atomic Mass Evaluation and the Mass Tables

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The new evaluation of the Atomic Masses, AME2012, has just been released. It represents a major step in the history of the 60 year old Atomic Mass Evaluation based on the method developed by Wapstra. This new publication includes all material available to date. Some of the policies and procedures used in our evaluation are reported, together with an illustration of one specially difficult case, the energy available for the ^{102}Pd double-electron capture. The observation of the mass surface reveals many important new features. We illustrate this statement by the double magicity of ^{270}Hs at $N = 162$ and $Z = 108$.

I. INTRODUCTION

The Atomic Mass Tables are the fruit of the evaluation of all valid experimental data aiming at mass measurements, or in which relevant energy measurements are given. Among the various projects that originated in the 1950's, the concept developed by Aaldert H. Wapstra, proved to be able to face the otherwise insolvable difficulties due to the strong interconnections among the measurements. It was implemented in a Fortran program with the help of the computer engineers of Oak Ridge, under his supervision. This concept is the one that is referred to as the Atomic Mass Evaluation (AME). It was the only one which survived and produced a series of Mass Tables over the years, the most recent were published in 1983 [1], 1993 [2], and 2003 [3]. In December last year, the 2012 version was published in the journal "Chinese Physics C" [4, 5], together, as in 2003, with the NUBASE2012 evaluation [6]. Reprints from these publications were largely and freely distributed to all physicists who registered at the website of the new Atomic Mass Data Center (AMDC) in Lanzhou [7].

Due to the famous relation $E = mc^2$, the mass of a nuclide yields its binding energy, which results from the action of all the forces within that nuclide. It is therefore not a surprise that knowledge of nuclear masses may have an impact in so many different areas of physics: nuclear physics, the standard model, neutrino physics, astrophysics, atomic physics, and also metrology in view of the redefinition of the kilogram on a microscopic scale. For example, the knowledge of masses has played an important role in the discovery of isotopism in 1913, in solving the "age of the Sun crisis" in 1919, in discovering the first closed shells in 1933, nuclear deformation in 1954, magicity disappearance in 1974, and sub-shell closure in 1981. More details and some examples can be found in Ref. [8].

II. THE MASS DIFFERENCE BETWEEN ^{102}Pd AND ^{102}Ru

The AME has been largely described in many places [4, 5, 9, 10]. In the context of this conference, it seems more interesting to give a detailed description of one of the most difficult cases we have encountered when evaluating data for the AME2012. A case that is still not resolved concerns the mass difference between ^{102}Pd and ^{102}Ru, corresponding to the energy available for double-electron capture in ^{102}Pd. The precise knowledge of this quantity is of primordial importance in the search for a possible neutrinoless double-β decay in ^{102}Pd. The value presently accepted in AME2012 is 1171.9 (2.4) keV.

Until recently, there were two paths (Fig. 1) connecting ^{102}Pd to ^{102}Ru:

- One combines the β^- decay energy of ^{102}Rh to ^{102}Pd, $Q = 1150\,(6)$ keV [11], with three results connecting the same ^{102}Rh to ^{102}Ru, they are: two β^+ decay energy measurements by Ref. [11] (2317 (10) keV) and Ref. [12] (2325 (10) keV) and a (p,n) charge exchange reaction on ^{102}Ru –

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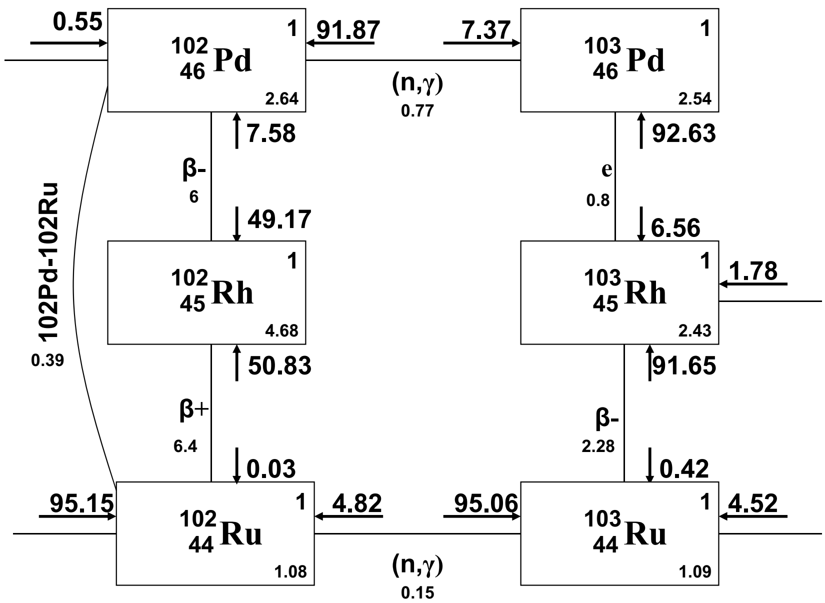

FIG. 1. "Flow of information diagram" displaying the three "paths" between ^{102}Pd and ^{102}Ru. Each square box represents an individual nuclide. Its mass precision (keV) is given in the lower right corner, and its degree of connection (see Ref. [4] p.1292 for full details) in the upper right corner. Along each connection between two nuclides is the type of relation, its precision and, on both sides, arrows which indicate the flow of information of that piece of data to the two connected nuclides.

3115 (15) keV [13].

- The second combines (see Fig. 1):
  - two very precise ^{102}Pd(n,γ) reactions: 7624.6 (1.5) keV [14] and 7625.6 (0.9) keV [15], pre-averaged to 7625.33 (0.77) keV;
  - two very precise ^{102}Ru(n,γ) reactions: 6232.2 (0.3) keV [16] and 6232.00 (0.17) keV [15], pre-averaged to 6232.05 (0.15) keV;
  - an electron-capture decay of ^{103}Pd 543.0 (0.8) keV [17];
  - four measurements of the β^- decay of ^{103}Ru: 764 (4) keV [18], 760 (6) keV [19], 762 (5) keV [20] and 769 (4) keV [21], pre-averaged to 764.6 (2.3) keV

The total mass differences between ^{102}Pd and ^{102}Ru derived using these two paths agree perfectly well with each other (1173.1 (8.8) keV compared to 1171.6 (2.5) keV, respectively).

Recently, the SHIPTRAP team at GSI [22] determined directly the ratio between the masses of these two nuclides by Penning trap mass spectrometry. Surprisingly, their result, obtained with a very high precision, yielded a mass difference of 1291.76 (0.39) μu (or 1203.27 (0.36) keV). The previous combination of reactions and decays represent all together an equivalent 1258.1 (2.6) μu. The new result is 8 times more precise, but stands at more than 10 standard deviations away from the previous one. In the course of our evaluation of the new result, we examined not only the Penning Trap work, but also the beta-decay and reaction studies, to try and find possible reasons for such a difference. However, no explanation could be found in any of the publications.

It would be tempting, in this context, to prefer the consistency of the two old paths to one single new measurement. However, it should be recalled that Penning trap measurements have up to now almost always been reliable and trustable. We also recall that the β energy measurements have shown to be less accurate for nuclides very far from stability due to missed levels, but were almost always very reliable close to stability where the energies involved are small.

Having found no reason to distrust any of the measurements involved here, and having on one side one result obtained with a very reliable method, on the other side with combination of several quite trustable measurements, we finally decided, for the AME2012 evaluation, to provisionally not use the new Penning trap result and to call for more measurements in order to clarify this issue.

III. ^{270}Hs: A NEW DOUBLY-MAGIC NUCLIDE

The regularity of the mass surface, observed in all places where no structures are known, allows the obser-