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Evaluations of Nuclear and Decay Properties

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Abstract. The ensemble of experimental data on the 2800 nuclides which have been observed to date are being evaluated, according to their nature, by different methods and by different groups. I shall first try a classification and then focus on the two "horizontal" evaluations in which I am involved: the Atomic Mass Evaluation AME and the NUBASE evaluation.

INTRODUCTION

Quite often in science, classification within a group of objects in a given domain appears to be useful. It is tempting therefore to propose a classification of the nuclear data that have been considered by different actors in nuclear physics. One could distinguish between data related to nuclides at rest (or almost at rest) and data related to nuclidic dynamics. In the first category one could consider ground state and levels properties, whereas the second would encompass reaction properties and mechanisms.

Nuclear ground state masses and radii; magnetic moments; thermal neutron capture cross-sections; half-lives, spins and parities of excited and ground-state levels; the relative position (excitation energies) of these levels; their decay modes and the relative intensities of these decays; the transition probabilities from one level to another;... all fall in the category of what could be called the "static" nuclear properties.

Total and differential reaction cross-sections; reaction mechanisms; spectroscopic factors;... could be grouped in the class of "dynamic" nuclear properties.

It is out of the scope of the present talk to cover all aspects of nuclear properties and nuclear data. The fine structure of "static" nuclear data will be shortly described and the authors of the various evaluations presented, before centering this talk on the two "horizontal" evaluations in which I am involved.

"STATIC" NUCLEAR DATA

The amount of data to be considered here is huge. Very early it was found convenient to organize their evaluation in a network, splitting these data according to the mass of the nuclides, the A-chains. Such a division makes sense, since most of the decay relations among nuclides are β-decays where A is conserved. This is, of course, less true for heavier nuclides where α-decay is the dominant decay-mode connecting an A-nuclide to an $A-4$ daughter. This structure is the one adopted by the Nuclear Structure and Decay Data network (the NSDD) organized internationally under the auspices of the IAEA in Vienna. An A-chain or a group of successive A-chains is put under the responsability of one member of the network. His or her evaluation is refereed by another member of the network before publication in the journal 'Nuclear Data Sheets' (or in the 'Nuclear Physics' journal for $A \leq 44$). At the same time the computer files of the evaluation (the ENSDF: 'Evaluated Nuclear Structure Data Files') are made available at the NNDC-Brookhaven [1]. In this evaluation network most of the "static" nuclear data are being considered.

The AME atomic mass evaluation

However, data related to the energy relations or energy differences between nuclides is more complex due to the numerous links, overdetermining the system and exhibiting sometimes inconsistencies among data. This ensemble of energy relations is taken into account in the 'horizontal' structure of the Atomic Mass Evaluation AME. By 'horizontal' one means that a unique nuclear property is being considered across the whole chart of nuclides, here the ground-state masses. Only such a structure allows to encompass all types of connections among nuclides, whether derived from β-decays, α-decays, thermal neutron-capture, reaction energies, or mass-spectrometry where any nuclide, e.g. ^{200}Hg can be connected to a molecule like $^{12}C^{13}C^{35}Cl_5$ or, in a Penning trap mass spectrometer, to ^{208}Pb.

In the AME, (n,γ) and (p,γ) reactions play a key-rôle since they provide many of the most accurate mass differences, helping thus in building the "backbone" of masses along the valley of β-stability.

The isomers matter and the NUBASE evaluation

At the interface between the NSDD and the AME evaluations, one is faced with the problem of identifying - in some difficult cases - which state is the ground-state. The isomer matter is a continuous subject of worry in the AME, since a mistreatment can have important consequences on the ground-state masses. When an isomer decays by γ-emission, there is no ambiguity and the assignment as well as the excitation energy is given by the NSDD evaluators. But when such γ-transition to the ground-state cannot be observed, most often a decay energy to (and sometimes from) a different nuclide can be measured (generally with less precision). In the latter case one enters the domain of the AME, where combination of the energy relations of the two long-lived levels to the daughters (or to the parents) with the masses of the latter, allows to derive the masses of both states, thus an excitation energy and, in general, an ordering.

Up to the 1993 mass table, the AME was not concerned with all known cases of isomerism, but only in those which were relevant to the determination of the ground-state masses. In AME'95 it was decided, after discussion with the NSDD evaluators, to include all isomers for which the excitation energy "is not derived from γ-transition energy measurements (γ-rays and conversion electron transitions), and also those for which the precision in γ-transitions is not decidedly better than that of particle decay or reaction energies leading to them" [2].

However, differences in isomer assignment between the NSDD and the AME evaluations cannot be all removed at once, since the renewal of all A-chains in NSDD can take several years. In the mean-time also, new experiments can yield information that could change some assignments. Here a 'horizontal' evaluation should help.

The isomer matter was one of the main reasons for setting up the NUBASE collaboration [3] leading to a thorough examination and evaluation of those ground-state and isomeric properties that can help in identifying which state is the ground-state and which states are involved in a mass measurement. NUBASE appears thus as a 'horizontal' database for several nuclear properties: masses, excitation energies of isomers, half-lives, spins and parities, decay modes and their intensities. Applications extends from the AME to nuclear reactors, waste management, astrophysical nucleo-synthesis and to preparation of nuclear physics experiments.

Other 'horizontal' evaluations

There might be other reasons for 'horizontal' evaluations. The splitting of data among a large number of evaluators, like in the NSDD network described above, does not always allow to have a completely consistent treatment of a given nuclear property through the chart of nuclides. Also some quantities may fall at the border of the main interest of such a network. This is the reason why a few 'horizontal' compilations or evaluations have been conducted for the benefit of the whole community. For example, one can quote the remarkable work of Otten [4] for isotope shift and hyperfine structure of spectral lines and the deduced radii, spins and moments of nuclides in their ground-state and long-lived isomeric states. An evaluation of isotope shifts has been published also by Aufmuth and coworkers [5], and a table of nuclear moments was given by Raghavan [6], updated by Stone [7]. More recent tables for nuclidic radii were published by Angeli [8] in 1991 and by Nadjakov *et al* [9] in 1994. Two other 'horizontal' evaluations are worth to be mentioned: the one for the isotopic abundances, by Holden [10]; and the evaluation of Raman and coworkers [11] for the energy E_{2^+} and the reduced electric quadrupole transition probability $B(E2)$ of the first-excited 2^+ state of even-even nuclides.

NEXT AME AND NUBASE EVALUATIONS

The most recently published mass table from the "Atomic Mass Evaluation" is of December 1995 (AME'95) [2]. Urgency in having the first NUBASE evaluation completed, deviated the planned update of an AME for 1997, since the two evaluators of the AME are also collaborators of NUBASE. The NUBASE evaluation was thus published for the first time in September 1997 [3]. In order to have consistency between the two tables, it was decided that the masses in NUBASE'97 should be exactly those from AME'95. The few cases for which new data required a change were only mentioned in the table and discussed in the accompanying text. The electronic ASCII files for the AME'95 and the NUBASE'97 tables, for use with computer programs, are distributed by the Atomic Mass Data Center (AMDC) through anonymous *ftp* and through the *World Wide Web* [12]. The contents of NUBASE can be displayed by a Java program JVNUBASE [13] through the *World Wide Web* and also with the NUCLEUS PC-program [14], all distributed by the AMDC.

In the future it is planned to have the AME and the NUBASE evaluations, which have the same "horizontal" structure and basic interconnections at the level of isomers, to be published together, the first time in a year from now. Such a publication is urgently needed, because of the impressive number of new results that were published since AME'95 and NUBASE'97, and also because some limitations in the policies accepted then, given the involved load, should be displaced or removed.

New results

It is not the subject of the present talk to give all the new results that are worth to be mentioned. I shall rather illustrate them through some important cases, the first two ones being strongly related to the theme of the present conference on capture gamma-ray spectroscopy.

Mass of the neutron: a five times more precise determination of the neutron-capture energy of ^{1}H at the ILL (0.4 eV) [15], combined to the masses of ^{1}H and of the deuteron yields a 3.7 times more precise mass of the neutron. The new (n,γ) energy is far outside the previously reported errors. The resulting new neutron mass is thus significantly lower (7 nu or 6.5 eV) than the value adopted in AME'95: $1\,008\,664.916\,3(6)\mu$u instead of $1\,008\,664.923\,3(22)\mu$u.

The ^{124}Te(n,γ)^{125}Te measurement: a new measurement connects ^{125}Te to ^{124}Te with a precision of 30 eV [16], 30 times better than an older value reported only in an abstract. The resulting new mass of ^{125}Te is 6 keV higher and fits much better with the other mass connections in the neighborhood, reducing thus several significant contributions to the total χ^2 of the mass fit [17]. This datum gives an idea of the importance of (n,γ) data in mass determination, since its influence alone moves the masses of nuclides as far as ^{131}Te and ^{131}Sn by as much as 1.3 keV.

Region of medium-A proton-rich nuclides: measurement of proton energies from decaying ground and isomeric states allow to determine ground state masses and isomeric excitation energies. Still more important, the proton intensities allow to derive the spins of the decaying states, giving thus a complete description of the involved levels [18 - 27]. Knowledge of proton separation energies beyond the drip-line is also very useful in estimating masses for nuclides for which no experimental data are available (the 'systematic' masses, flagged with #). These studies showed also that some previously observed decays of the daughters or grand-daughters of the studied nuclides did not belong to the levels assumed then, resulting in important changes in several ground-state masses.

Mass-spectrometric measurements of exotic nuclides: the now well known ISOLTRAP Penning trap spectrometer yielded several new masses of ground-states and isomers for Hg isotopes [28] and other proton-rich nuclides around Pb [29]. Also the SPEG spectrometer at GANIL measured new masses of very short-lived nuclides [30], improving our knowledge of nuclear structure around $N = 28$. But the most eagerly awaited results, that should certainly be published shortly and for which we have already exciting information from private communications, are from the two new spectrometers on-line: MISTRAL [31] at CERN and the GSI-ESR at Darmstadt [32].

Discovery of new very heavy elements: since 1995, new isotopes have been discovered for elements 112, 114, 116 and 118, and up to mass number 293 for the latter [33 - 34]. Their measured α-decay energies allow to make fair estimates of the masses of nuclides rather far beyond the heaviest $A = 273$ nuclide in AME'95.

Existence of ground-states deduced from systematics: in NUBASE'97 several cases occured where the existence of an unknown ground-state, while only one long-lived state was reported, was infered from systematics of isomers in neighboring nuclides. A typical example is ^{161}Re, for which NUBASE'97 predicted a $1/2^+$# proton emitting state below an observed 14 ms α-decaying high-spin state. Since then the 370 μs, $1/2^+$, proton emitting state was reported with a mass 124 keV below the 14 ms state for which a spin $11/2^-$ was assigned [21]. Similarly, the recently discovered $11/2^-$ bandhead level in ^{127}Pr [35] is almost certainly an excited isomer that can be estimated from systematics to have an excitation energy of 600(200)# keV and to have a half-life of approximatively 50# ms.

New policies

The last example above is illustrative of one of the policies already applied in NUBASE'97 for estimating still unknown quantities from (short) extrapolations in neighboring nuclides. The general symbol used to flag such estimated quantities is '#' all across the table.

Half-lives: in the next publication, estimates for half-lives will be given everywhere when possible (generally for β-decaying nuclides). A special category is for nuclides which were identified at accelerators, after reaction with a target. At the place of the half-life NUBASE'97 gave a lower-limit for this quantity deduced from the time-of-flight between the target and the detectors. This true experimental information was not found to be convenient, since in most cases the time of flight is order of magnitudes shorter than the expected half-life. Instead, an estimated half-life will be given; and, in order not to loose the information on the identification, the time-of-flight lower limit will still be given in NUBASE.

Selection of isomers: in NUBASE'97 we considered only "excited states that live longer than 1 millisecond". This limit is quite acceptable when β-decaying nuclides are considered, satisfying thus the needs of most astrophysical nucleosynthesis calculations and nuclear reactors calculations. It has however serious inconveniencies when proton and α decaying nuclides are to be considered, a large number of which have much shorter half-lives for both ground-states and excited isomers. Also in the experiments discussed in the previous paragraph, isomers with half-lives as short as the time-of-flight can reach the detectors. These experiments would therefore benefit to have these isomers also listed in NUBASE. We therefore plan to lower the limit for the selection of isomers to 1 μsecond, adding then some 300 items, or even 100 nanoseconds with another 300 isomers.

Naming of the the transfermium elements: the names and the chemical symbols of the elements 104 to 109 in AME'95 and in NUBASE'97 were based on a provisional recommendation of the Commission on Nomenclature of Inorganic Chemistry of the International Union of Pure and Applied Chemistry (IUPAC). The official report has been published since then [36], and differs noticably from the former. The official names will be used in all future publications.

First E_{2^+} for even-even nuclides: this information is the earliest indicator of nuclidic shape. It was already available in our files when NUBASE'97 was published, and is displayed by JVNUBASE [13] and the NUCLEUS PC-program [14]. It will be given in the next NUBASE publication.

Year of discovery: the same is true for this information which can be useful for educational purpose. It was not given in NUBASE'97 because it was not completely checked at that time. If there is interest in the community for this information, it will be included in the next NUBASE.

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