Theoretical study of forbidden non-unique beta transitions

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Abstract

Over the past decade, forbidden non-unique beta transitions have been identified to be of critical importance in several fundamental physics topics, such as the modelling of antineutrino flux from nuclear reactors or from the Earth, and the background modelling in dark matter experiments. The decay half-lives of long-lived beta-emitting radionuclides, which are typically highly forbidden transitions, are of importance for geo- and cosmo-chronology. These half-lives are determined by means of activity measurements that must be very accurate. In radionuclide metrology, the BIPM (International Bureau of Weights and Measures) has recently developed a new extended international reference system (ESIR) for establishing primary standards of pure beta-emitting radionuclides, based on the liquid scintillation counting technique. The beta spectrum is an essential input to decisively establish the primary activity of the sample. More generally, a better knowledge of these transitions is also of interest to improve the quality, the completeness and the accuracy of nuclear decay data.

Contrary to allowed and forbidden unique transitions, it is essential to take into account the nuclear structure of the initial and final states involved in forbidden non-unique transitions. This situation significantly complicates the formalism and the calculations. Realistic nuclear structure calculations are usually time demanding and require a certain expertise. The transitions can strongly depend on relativistic matrix elements that necessitate relativistic nuclear wave functions, while nuclear structure models are usually non-relativistic. A code that treats these transitions, which is fast and simple to use for a non-expert, is currently unattainable.

The present contribution will describe our recent work on the calculation of the forbidden non-unique beta transitions. Realistic nuclear structure information (one-body transition densities) has been determined in the non-relativistic shell model with the NushellX code, which makes use of Hamiltonians fitted to experimental data in different mass regions. The Behrens and Bühring formalism has been studied in detail and specific codes have been developed in order to treat the forbidden non-unique transitions. Several forbidden non-unique transitions, of differing degrees, have been compared to precise measurements. The sensitivity of the spectra to different assumptions has been studied: simplified or full numerical lepton current; determination of the relativistic matrix elements with the conserved vector current (CVC) hypothesis; and methods for determining Coulomb displacement energies. A summary of these results will be presented.