Superallowed Fermi decays: precise $T_{1/2}$ and branching ratio measurements

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INTRODUCTION

Through the studies of Fermi transitions between $\mathbf{0^+}$ analog states with $\mathbf{T = 1}$ (superallowed transitions), nuclear physics provides a valuable test of the Standard Model of particle physics [1]. These transitions depend only on the vector part of the weak interaction, and according to the conserved vector current (CVC) hypothesis, their strength ***Ft*** is a constant. Then this value is used to determine the V_{ud} term in the CKM quark mixing matrix, that should be unitary.

The constant ***Ft*** strength determination requires very high precision measurement of the decay energy Q_{EC} (related to masses) and of the partial half-life of the transition (parent nucleus half-life $T_{1/2}$ and branching ratio ***BR***), but it also requires some theoretical corrections of the experimental values. Then, beside the search for "new physics" if deviations from the standard model are observed, such studies are a very sensitive test of the theoretical descriptions used to calculate those corrections.

A recent review that summarizes all the physics context and the efforts made in that field is given in ref [1]. The present proceeding will focus on recent experimental results concerning the $T_{1/2}$ and ***BR*** measurements that we performed at Jyväskylä university (for ^{26}Si, ^{30}S, ^{42}Ti and ^{62}Ga) and ISOLDE at CERN (for ^{38}Ca).

The different cases presented here will be used to describe the experimental challenges to achieve the required level of precision, which is of the order of few 10^{-4} for half-lives and Fermi transition branching ratios.

EXPERIMENTS DESCRIPTION

In all cases, the measurement consists on the repetition of a measurement cycle during which the isotopes of interest are accumulated on a tape, the decay of the isotopes is measured and the activity is evacuated by moving the tape.

The decay events are identified using a beta-particle detector : either a plastic scintillator as used in Jyväskylä experiments (fig. 1), either a Geiger counter as used at CERN. The decay events are registered on both a fast multi-scaler type acquisition system, either on a list-mode type VME system, that allows to store β-γ coincidences events, using germanium detectors for gammas, in addition to the beta counter. Each event is registered with a time stamp relative to the measurement cycle, to build decay time spectra for each cycle.

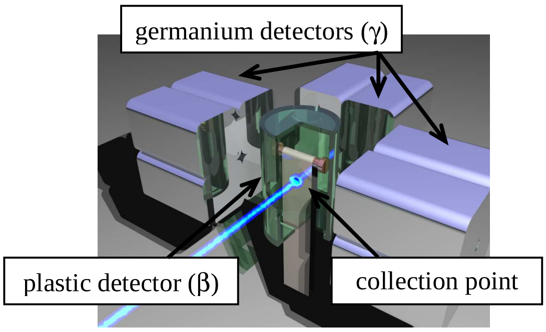

FIGURE 1. Schematic view of the experimental setup used in Jyväskylä experiments: the isotopes are deposited on the tape and the collection point is surrounded by the beta detector. Germanium counters are used to measure the gamma de-excitation for branching ratio determinations.

HALF-LIVES MEASUREMENTS

The half-lives are resulting from the analysis of time spectra from all measured cycles. In order to reach a precision better than 10^{-3}, only from a statistical point of view, at least 10^6 to 10^7 events have to be registered. The basis of the analysis is a fit, cycle by cycle, of the exponential decay curve, including a background signal. Due to this background, the measurement has to be performed on a time window that is at least of the order of 15 to 20 times the half-life to be estimated, to ensure a good precision of the fit.

The first correction needed is then the data acquisition (DAQ) dead-time correction. For the multi-scaler DAQ this dead-time is chosen to typically 2 and 8 μs. For the VME DAQ, it is forced to a fixed value of 100 μs. The correction applied with different dead-times must lead to the same value of the estimated half-life. In this way, we measured the half-life of ^{62}Ga : 116.09 ± 0.17 *ms* [2].

During the accumulation of isotopes on the tape, there may also be accumulation of some mass contaminant and of the daughter nucleus, either as contaminant, either due to the decay during accumulation phase. If the daughter/contaminant half-life is very long compared to the isotope of interest, its contribution can be treated as background, but if it is not the case, it has to be properly separated from the background. To achieve this, a short time in the beginning of each cycle is devoted to a background measurement, before any activity has been collected on the tape. This was necessary in the case of ^{30}S half-life, for which we obtained 1175.9 ± 1.7 *ms* [3].

Nevertheless, if the daughter half-life has the same order of magnitude than the parent half-life, the fitting algorithm is not able to separate both contributions. This is the case for the decay of ^{42}Ti for which the daughter (^{42}Sc) half-life is only about 3 times longer. In such cases, the solution is to accumulate the isotopes in a purification trap. Then a pure sample is extracted at the beginning of the measurement, and the amount of daughter decay is constrained only by the parent decay. In the case of ^{42}Ti, we determined a half-life of 208.14 ± 0.45 *ms* [4], using JYFLTRAP. The same kind of measurement was performed at ISOLDE with ISOLTRAP for ^{38}Ca, and a half-life of 443.8 ± 1.9 *ms* [5] could be deduced.

Using the same technique, we measured the half-life of ^{26}Si: 2228.3 ± 2.7 *ms* [6]. An independent experiment performed at Texas A&M University leaded to another result: 2245.3 ± 0.7 *ms* [7]. The disagreement between the two values is very important with respect to the quoted uncertainties, and the reason for it is not yet clearly known. Nevertheless, a possible cause could be the very small difference of the detection efficiency for beta particles coming from the parent or the daughter decay. This effect must be corrected with the help of simulations.

BRANCHING RATIO MEASUREMENTS

The branching ratio of the $0^+ \rightarrow 0^+$ analog transition is estimated by measuring the non-analog feeding to other states, by mean of β-γ detection. The part of the strength feeding the isobaric analog state is a critical aspect for precision measurement.

If only ~0.1% of the decay is non-analog, then a 25% error on the β-γ intensities will result only in a 0.025% error on the analog feeding. This is the situation for the decay of T_Z=0 nuclei, and we could thus measure the analog BR for ^{62}Ga : 99.893 ± 0.024 % [8]. For the decay of T_Z=1 nuclei, the non-analog branching is much more significant (~25% for ^{26}S and ^{30}S, ~50% for ^{42}Ti). Then, to achieve a precision of 10^{-3} on the BR, the same precision must be achieved on the β-γ intensities. This requires to characterize the γ detection absolute efficiency at the 10^{-3} to 10^{-4} level. An important work on this difficult aspect is done at Texas A&M University and has also started at CENBG.

In addition, due to the relatively low efficiency of germanium detectors, and depending on the β-γ intensities, a higher statistics is required than for half-lives (10^2 to 10^4 times more).

CONCLUSION

The high precision measurement of half-lives and branching ratios for the study of super-allowed Fermi transitions is a typical physics case for ISOL facilities. Our recent results are now partially included in the world averages. In order to go further, either for heavier T_Z=0 cases, either to improve the precision of the branching ratios for T_Z=1 nuclei, a current limitation is the production rate of these isotopes (or detection efficiency). Future facilities like EURISOL should offer a solution to this problem.

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