ELECTRONIC TECHNIQUES IN TIMING MEASUREMENTS FOR NUCLEAR STRUCTURE

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Prezenta lucrare descrie în detaliu două metode pentru determinarea timpilor de viață ai stărilor nucleare excitate. Metoda "Fast Timing" descrisă în cele ce urmează, este o metodă foarte sensibilă, ajungând să măsoare timpi de viață de la picosecunde până la sute de nanosecunde şi se bazează practic pe coincidența triplă β–γ–γ. Cea de-a doua metodă prezentată aici se bazează pe metoda spectrometrului monocristal, metodă mai puțin sensibilă în comparație cu metoda descrisă anterior, cu o sensibilitate de ordinul zecilor de nanosecunde şi mergând până la sute de microsecunde, dar având totuşi avantajul eficacității mari de detecție, datorită configurației monocristal utilizate. În cele ce urmează vor fi prezentate şi rezultate experimentale.

The present paper describes in detail two electronic methods for determining lifetimes of the excited nuclear states. The Fast Timing Method described below is a very sensitive method for lifetime measurements in a range spanning from tenths of picoseconds to hundreds of nanoseconds and it is basically based on triple β–γ–γ coincidences. The second method presented here is based onto the Single Crystal Scintillation Time Spectrometer method, less sensitive than the previous one, with a sensibility spanning from tenths of nanoseconds to hundreds of microseconds, but having the advantage of high detection efficiency, due to its single scintillation crystal configuration. Experimental results will be presented.

Keywords: timing measurements, nuclear structure, beta decay

1. Introduction

A crucial point in nuclear structure studies implies the comparison of measured nuclear properties with the model predictions. One of the most important nuclear structure parameters is the absolute transition probability of an electromagnetic decay of a discrete level, a quantity directly related with the lifetime of the decaying level. To compare these observables, the models predict the reduced transition probabilities. We describe and test two innovative electronic methods for measuring these lifetimes.

Measuring the lifetime of a nuclear level by electronic methods implies the detection of the electromagnetic radiations feeding and decaying that level, and

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the measurement of their time difference. For this purpose one has to use very sensitive detection system and signal processing electronics. As follows, I will present two electronic methods of measuring lifetimes, methods used by the author in experiments at the Bucharest FN Tandem and abroad. The first method is called the "Fast Timing Method" (FTM) [1, 2] and it is used to determine lifetimes in the range spanning from tenths of picoseconds to hundreds of nanoseconds, and the second method called "Single Crystal Scintillation Time Spectrometer" technique (SCSTS) [3] has the advantage of high detection efficiency and it is used to determine lifetimes from nanoseconds to hundreds of microseconds.

2. The fast timing method (FTM)

The FTM is designed to be used in the „off-line" gamma spectroscopy decay experiments. This method is based on the measurements of the time difference between the beta radiation feeding a nuclear excited level and the gamma radiation decaying that level (see the generic level scheme from Figure 1) [4]. In order to efficiently measure these two radiations, it is important to minimize the statistical fluctuations associated with the timing response (time jitter), and the energy dependence response (time walk). In order to fulfill these conditions we used detectors with short rise time for the output pulse. The principle of the FTM is presented in Figure 1. A thin plastic scintillator was employed to detect the beta particles. The signal from this detector is used as a start for the timing measurement. The ΔE signal is virtually independent of the beta particle energy loss in the thin plastic detector, generating a clean start signal.
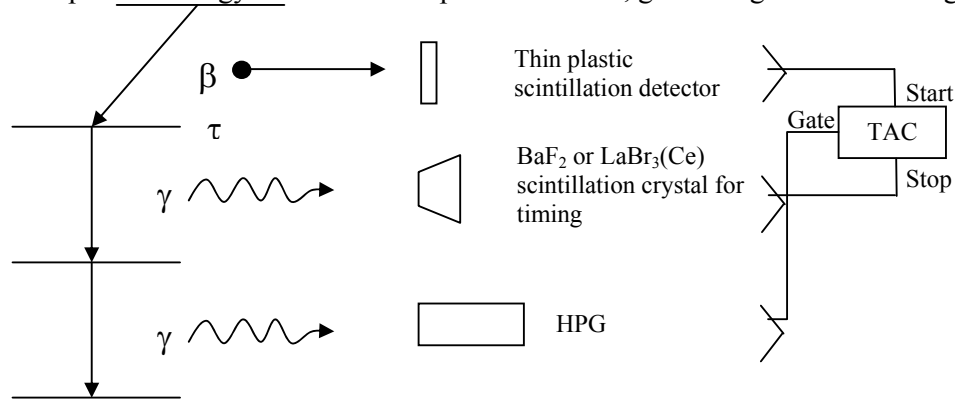

Fig. 1. The principle of the fast timing method for measuring the lifetime of the excited state labeled with "τ". The HPGe detector is used for its energy resolution in order to isolate the gamma cascade.

We used an NE111 plastic scintillator having a 200 ps rise time and 1.7 ns decay time.

A fast scintillation crystal is used for gamma detection. We used BaF_2 and $LaBr_3(Ce)$ crystals having very good time response (~200 ps decay time). Although the time response of this type of detectors is very good, the energy resolution is poor (~50 keV for 1 MeV gamma rays). For this reason we need to use an HPGe detector in order to isolate a certain gamma cascade.

The time spectrum is a convolution of the prompt peak (having the width "w") and the slope generated by the lifetime "τ" (Figure 2 a)). The spectra can be analyzed by two methods: (i) "slope" and (ii) "centroid shift" methods. A schematic representation of these two methods is shown in Figures 2 b), c). When the lifetime is very short, the time spectrum suffers a displacement of the centroid with respect to the prompt peak. With a proper time calibration, the lifetime can be extracted from this shift. If the lifetime is long, the resulting slope from the time spectrum can be fitted with an exponential curve in order to extract the lifetime.
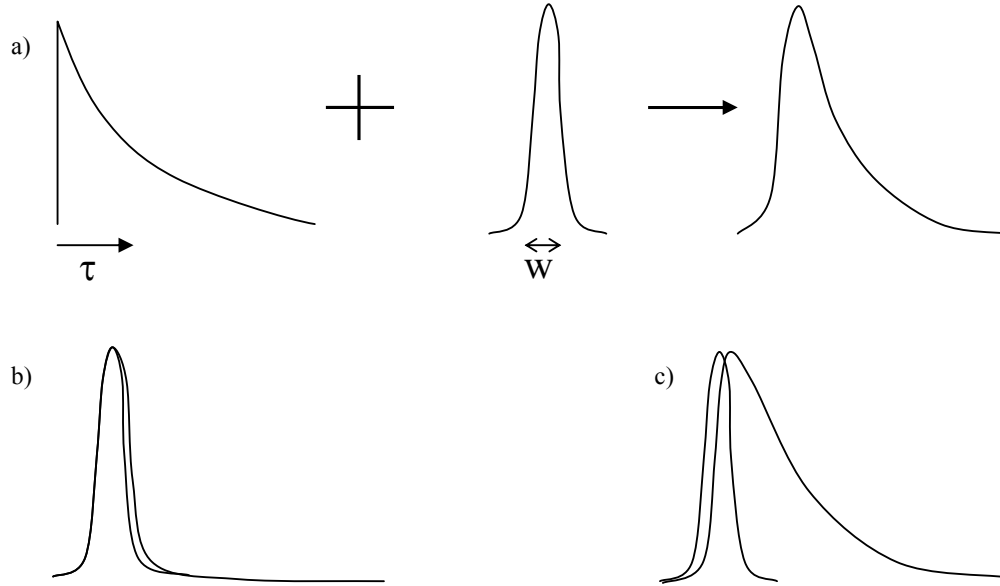

Fig. 2. Data analysis in the FTM experiments. a) The resulting curve in the time spectra is a convolution of the prompt time peak and the slope generated by the lifetime; b) Representation of the centroid shift method ($\tau \ll w$); c) Schematic representation of the slope method ($\tau > w$). See text for discussion.

A real experiment employing the FTM was performed at the OSIRIS mass separator at Studsvick [5]. The study aimed to determine the lifetimes of the excited states in the ^{124}Sn and ^{124}In nuclei. These nuclei were mass separated from

the fission products obtained in a uranium target exposed to a neutron flux from a reactor. The separated nucleus was the ^{124}Ag. The chain of decays was:

$$^{124}Ag \xrightarrow{\;0.172\,s\;} {}^{124}Cd \xrightarrow{\;1.25\,s\;} {}^{124}In \xrightarrow{\;3.7\,s\;} {}^{124}Sn$$
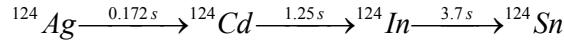
The detection setup was assembled from two HPGe detectors, one BaF$_2$ detector and one thin plastic detector (NE111).

An important result obtained in this experiment was the lifetime of the 2578 keV state in ^{124}Sn. The result is represented in Figure 3, and the value of the lifetime was:

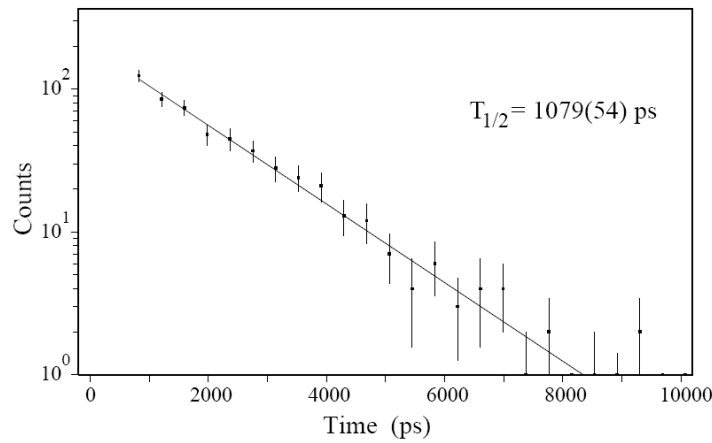$$\tau = \frac{T_{1/2}}{\ln 2} = \frac{1079(54)}{\ln 2} = 1556(77)\,ps\,.$$

Fig. 3. The 1079(54) ps half-life of the $8^{(+)}$ state at 2578 keV in the ^{124}Sn nucleus, measured by FTM technique, by de-convoluting the prompt peak from the useful slope generated by the long lifetime

The lifetime was determined using the slope method and the lifetime was extracted by making the de-convolution between the prompt peak and the slope generated by the studied lifetime. The spectrum was fitted using the programs developed specially for this type of experiments, and the condition for a good fit and for a very precise determination of the lifetime was to keep the χ^2 parameter as low as possible (the χ^2 for the present fit was 0.48).

3. The Single Crystal Scintillation Time Spectrometer technique (SCSTS)

The Single Crystal Scintillation Time Spectrometer (SCSTS) technique allows determining lifetimes in the range of nanoseconds to hundreds of microseconds. The detection configuration of this technique also permits the measurements of weak activities. The central point making this technique singular is the fact that it employs a single scintillation crystal.
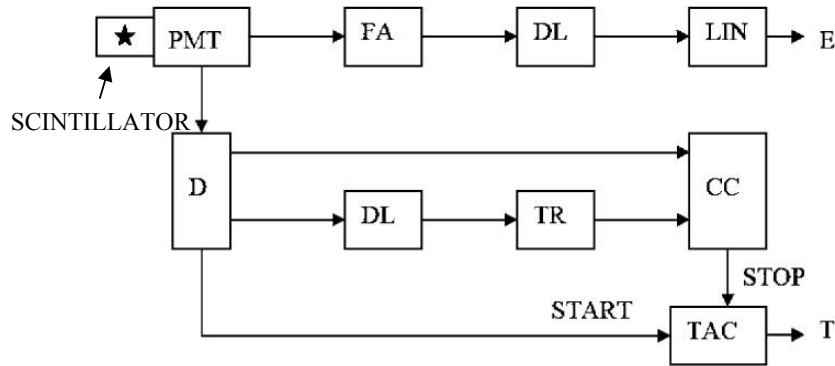

Fig. 4. The block scheme of the SCSTS experimental setup. The system is composed from a scintillator coupled to the PMT, discriminator (D), delay module (DL), trigger module (TR), coincidence unit (CC) and time to amplitude converter (TAC).

The SCSTS experimental setup consists in a scintillation detector and a spectrometric chain, represented schematically in Figure 4. The start signal of the TAC is given by the feeding transition of the state of interest and the stop signal is generated by the decaying one.
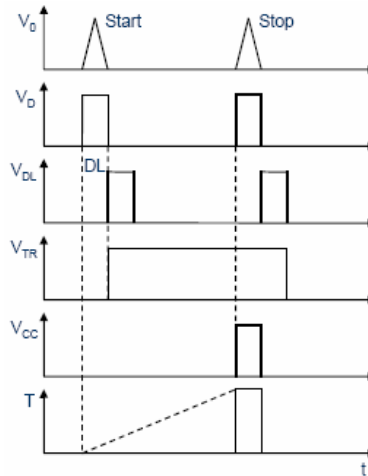

Fig. 5. The signal succession in SCSTS system. See text for discussion

The detector is made from a single plastic scintillator coupled with a photomultiplier tube. Only one output line is used from the last dynode of the PMT. In this case, the challenge is to distinguish between the start and the stop signals. The signals succession is represented graphically in Fig. 5.

The start and the stop signals are collected on a single output and are processed in a constant fraction discriminator (D). After that, the signals are delayed (DL) and these delayed signals enters a trigger module (TR) that has a logic output with adjustable lengths (depending on the lifetime to be measured). In the coincidence module (CC), the prompt signals from the detector are combined with the trigger signal, in order to isolate a clean stop signal. At the start of the TAC module appears any signal from the detector as start signal. The stop signals are only those clean signals resulted from the coincidence unit.
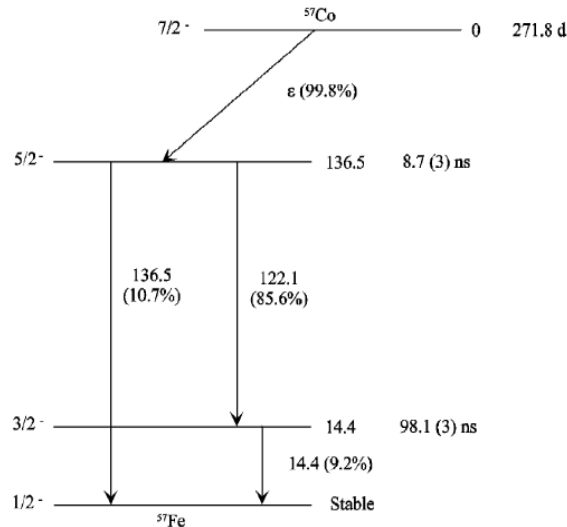

Fig. 6. The ^{57}Co decaying to the excited states of ^{57}Fe and the lifetimes to be measured as a test for SCSTS method (on the right side of the levels)

As a test for the SCSTS method we used a ^{57}Co source. The ^{57}Co nucleus beta decays on the excited states of ^{57}Fe as can be seen in Figure 6. The ^{57}Co source decays to ^{57}Fe with a half life of 271.8 days. The ^{57}Fe nucleus has two short lived isomeric states at 14.4 and 136.5 keV.

From the measure with the SCSTS technique described in this work were obtained $T_{1/2}$=8.0(9) and 94(4) ns, very close to the $T_{1/2}$=8.7(3) and 98.1(3) ns for 136.5 and 14.4 keV states, respectively. The last values are standard and reported in nuclear databases.

The present method is very efficient in measuring samples with low activity due to the implantation of the radioactive source into the detector. The method has a severe drawback with the so called "after-pulse" distribution [3].

The after-pulses generated in the detector are electron cascades on the dynodes, appearing after the main pulse, due to the atomic excitation in the dynode material.
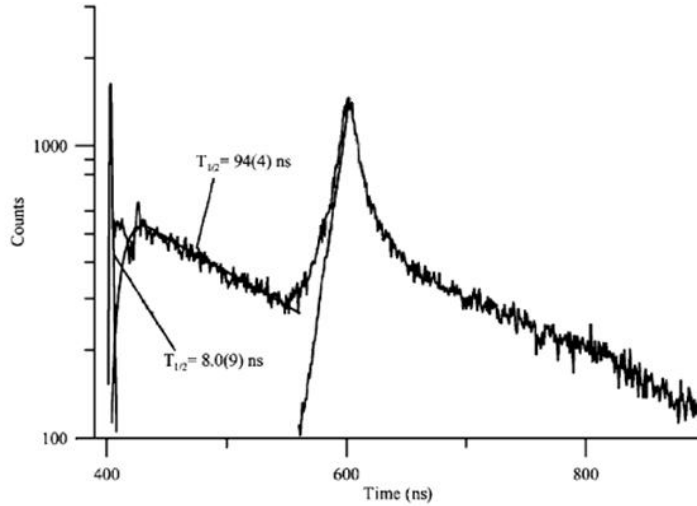

Fig.7. The half-life of the two isomeric states measured with SCSTS. The "after-pulse" distribution is represented by the peak on the right side of the spectrum

The after-pulse distribution can be observed in Figure 7, in the peak on the right side of the spectrum. Usually this effect disturbs the measurement and it can be eliminated from the spectrum by using not one, but two photomultipliers coupled to the same plastic scintilator, in a coincidence scheme. The after-pulses generated in each photomultiplier tube are not coincident as the real events are, and the time distribution can be therefore isolated [3].

4. Conclusions

The timing measurements described in the present paper are suitable for measuring lifetimes of isomeric states in a wide range of decay experiments involving low activities. The FTM is a very sensitive method allowing us to measure lifetimes in picoseconds range. The FTM configuration presented in this work is suited only for β^- decay experiments. The SCSTS method provides lower sensitivity (nanoseconds to microseconds range) from the point of view of the timing measurement, but can provide very high detection efficiency due to its 4π configuration.

Both methods were tested in real experiments and will be intensively used in future "off-beam" nuclear spectroscopy studies.

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B I B L I O G R A P H Y

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