IMPROVED EXPERIMENTAL METHOD FOR HALF-LIFE MEASUREMENTS BY ELECTRON — ELECTRON DELAYED COINCIDENCES

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ABSTRACT — A new method for accurate determination of instrumental time delays in measurements of half-lives using an electron magnetic spectrometer is presented. Lifetimes of the order of 100 ps can be obtained from curves of the centroid vs energy. For the $^{3}/_{2}+$ level in ^{203}Tl, the remeasured period value is 266 ± 13 ps.

1 — INTRODUCTION

The measurement of lifetimes of nuclear excited states is of great importance in experimental nuclear spectroscopy to test the nuclear models.

In the low energy region (≤ 1 MeV) the unstudied decays are complex and the lifetimes expected to be less than a few hundred picosecond. Therefore, the delayed coincidence method by centroid shift (between the radiation that creates the excited state and the radiation that annihilates it) is the best experimental method, provided it obeys the following three conditions:

i) good resolution in energy;

ii) time resolution as short as possible;

iii) use of theoretical and experimental methods which allow the correct calculation of the inevitable shifts in time, connected with the process of measurement and the energy difference between the radiations in study.

A compromise between conditions i) and ii) can be achieved by the delayed coincidence methods in electron - electron cascades using a double lens magnetic spectrometer equiped with plastic crystals associated with photomultipliers and fast electronics.

When the experiments are performed with such a magnetic spectrometer two main methods have been proposed to minimize the error in iii): a) pre – acceleration of the electron emitted by the source in such a way that the coincidences in time are measured between radiations of equal energy [1]; b) theoretical corrections of the shifts in time when the relative difference of the energies ($\Delta E/E$) of the radiations is small. However this method is quite restrictive. For example, for electron energies around 200 keV and differences of $\Delta E = 30$ keV the error introduced is approximately 30 picosecond [2].

We have developed an experimental method to correct those shifts in time, making them independent of $\Delta E/E$. Our method is applicable for electron-electron coincidences and we have made beta – conversion electron coincidences. The energies are in the range 50–600 keV. A similar, though more restrictive method, was used by Lindskog and Svensson [3].

The purpose of this paper is to present our method and the results obtained in the determination of a well known lifetime.

2 — EXPERIMENTAL PROCEDURE

The experimental arrangement is formed by a double lens Gerholm magnetic spectrometer equipped with plastic crystals NE 111 and photomultipliers RCA 8850. Constant fraction time discriminators Ortec 463 and conventional fast-slow coincidences installation with a time-to-amplitude converter Ortec 437 A are used. This allows the determination of the centroid of the fast-slow coincidence curve, by selecting one region of the continuous beta spectrum in coincidence with the internal conversion electron. By systematic selections of successive regions of the continuous beta in one of the lenses and tocusing the conversion electrons in the other lens we can measure the shift of the centroid of the fast-slow coincidence curve as a function of the selected beta energy. Reversing the selec-

tion of the energies in the lenses can, then, construct the β-e_k and e_k - β curves of the centroid shift as functions of the selected beta energies. By β-e curves we mean that the start and stop input of the

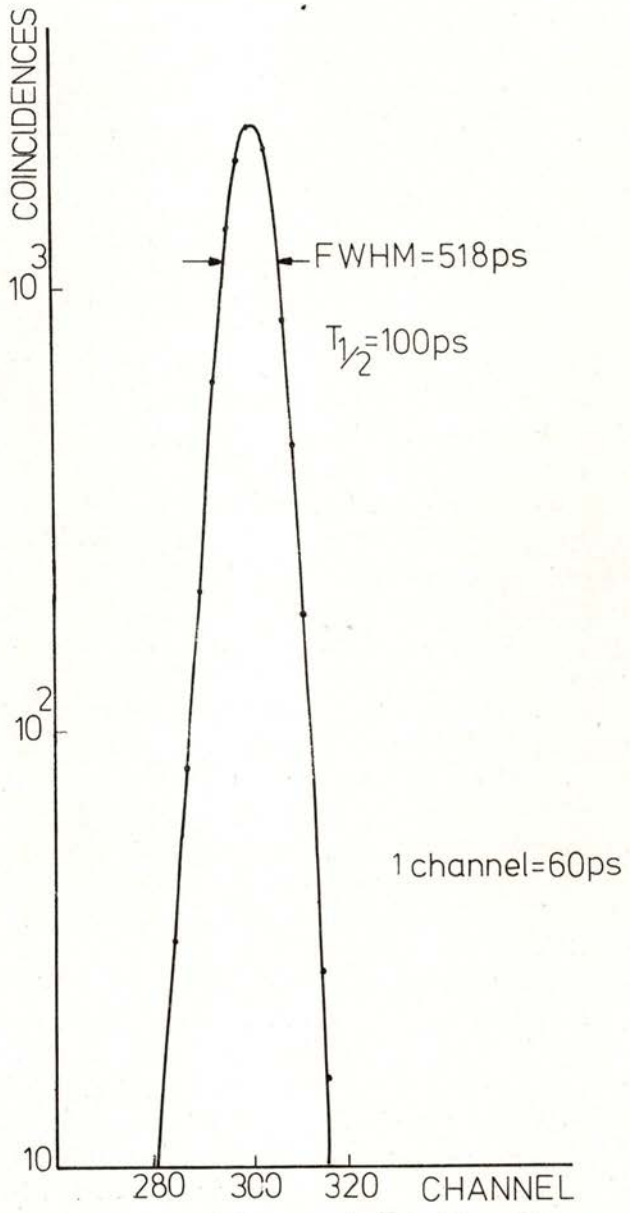

Fig. 1 — Prompt resolution curve obtained with a ^{198}Au source.

TAC are triggered respectively by the β-radiation and the conversion electron beam. In this way we have experimentaly determined the systematic errors introduced in the lifetime measurements discussed by Lindskog et al [2], i.e., 1) the energy dependence of the scintillator, 2) the time of flight of the electrons in the spectrometer, 3) the transit time variations due to small changes in either the electron momentum or in the magnetic field strength, 4) the electron transit time in the photomultiplier due to changes in the magnetic field.

3 — MEASUREMENTS

The experimental correction curves of the centroid shift in function of the energy were obtained with the cascades beta-conversion electron from the nuclides ^{203}Hg and ^{198}Au. The resolution time of the experimental arrangement was determined from ^{198}Au prompt beta-electron conversion curve (Fig. 1). The resolution time measured is 518 ps and the slope is 100 ps. Fig. 2 shows the results of coincidence experiments between continuous beta and K or L conversion electrons using a source of ^{198}Au. An identical behaviour for the e_k and e_L coincidences in the selected range of energies was obtained.

To cover the mentioned range of energies the cascades of two different nuclides, ^{198}Au and ^{203}Hg, were used. These results (Fig. 3) show the same systematic behaviour as the curve in Fig. 2.

Curves of second order could be well fitted by our experimental values. However to obtain small dispersion in the results of lifetime measurements it is necessary to start the fits with different sets of experimental values. We used four sets and obtained a dispersion of the order of 3%.

Using this correction methods we measured the lifetime of the 3/2+ state of ^{203}Tl by centroid shift. In this case the self-comparison technique is not adequate since the beta end point (208 keV) is quite near the electron conversion energy (193 keV). Experimentally we measured the beta (140 keV) − e_K (193 keV) and e_K (193 keV) − − beta (140 keV) coincidences. The difference of the centroid positions should give twice the value of the lifetime (τ), if there were no systematic errors due to the differences of the electron energies

focused in each lens on reversing the selected energies. In fact we have

$$2\tau = C_1 - C_1^* + \varepsilon_1 + \varepsilon_2$$

where C_1 and C_1^* are the centroid positions mentioned above and ε_1 and ε_2 the values given by the curves of Fig. 3, taking into account the difference of the electron energies selected in each lens. So, ε_1 corresponds to the value determined from the curve β-e_K and ε_2 to the value determined from the curve e_K-β.

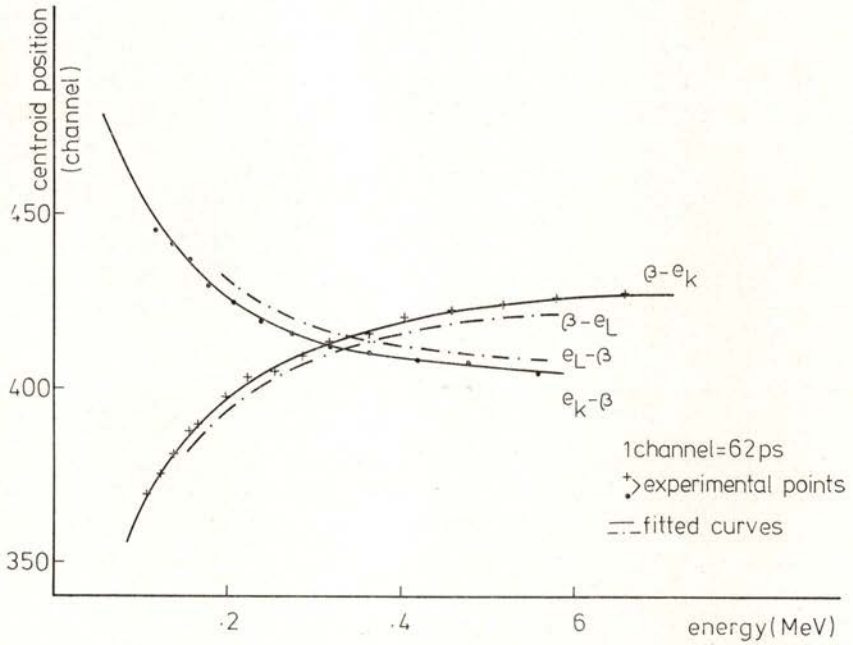

Fig. 2 — Instrumental centroid shift of the fast-slow delayed coincidence curves vs. beta energy. The curves correspond to β-L and β-K conversion electron coincidences.

The average lifetime obtained from the three sets of measurements with different sources is

$$\tau = 384 \pm 18 \text{ ps}$$

and thus

$$T_{1/2} = 266 \pm 13 \text{ ps} \quad ;$$

the overall error includes the error in the calibration with a time calibrator Ortec 462 (1.2 ps), the statistical error and the uncertainty from the determination of the systematic shifts (3 %).

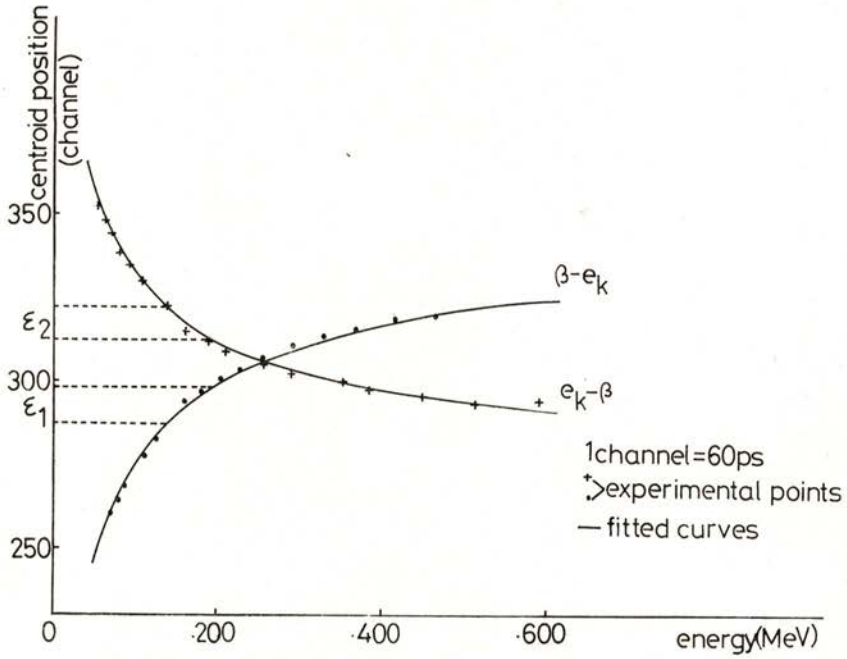

Fig. 3 — Instrumental centroid shift of the fast-slow delayed coincidence curves vs. beta energy. The sources ^{203}Hg and ^{198}Au were used. The curve obtained with ^{203}Hg was normalised to the curve with ^{198}Au, thus covering the range 50-600 keV.

4 — CONCLUSION

The result obtained for the half-life of the 3/2 + level in ^{203}Tl is in good agreement with the adopted value (278 ± 2 ps) [4], which we have remeasured by β-γ delay coincidences with NE 111 plastic crystals. The curve of the β-γ coincidences in ^{198}Au was used as reference source. Both the moments and the convolution methods were applied.

The value obtained through the moments method was:

$$T_{1/2} = 275 \pm 8 \text{ ps}$$

The convolution of the curves led us to

$$T_{1/2} = 274 \pm 6 \text{ ps} \quad .$$

This measurement was performed without the use of the magnetic spectrometer but with the same experimental equipment. It should be noted that it was possible to use such methods and detection processes due to the simplicity of the ^{203}Hg decay scheme; the greater complexity of the majority of the decays requires an accurate energy resolution, which can only be achieved by means of the magnetic spectrometer. We adopted the convolution model discussed in reference [5] though the results were identical if we carried out the calculations according to the Hutcheon model [6] The model proposed by Kim [7] led us to a higher value (295 ± 6 ps). This seems to be in accordance with the remarks of Lima et al [8].

The above described process of measuring the instrumental shifts makes it possible to measure half-lives even when the self-comparison method is not applicable. Moreover it does not require theoretical corrections such as Lindskog's, which have proved inadequate in many cases.

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