

LIFETIMES OF EXCITED NUCLEAR STATES ARISING IN THE α -DECAY OF Ra^{223} AND Bi^{211}

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1970

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Abstract

Full Text

UDC 539.144.6:539.1.083

PHYSICS

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In the region of heavy α -active nuclei one may expect that most excited states have lifetimes of the order of $10^{-10} \div 10^{-12}$ sec. ⁽¹⁾. In this region of nuclei, existing methods for measuring short lifetimes have a number of substantial limitations. We have used a microwave method developed in our laboratory ⁽²⁻⁵⁾. A block diagram of the apparatus is shown in Fig. 1. The apparatus consists of two temporal microwave shutters—for α -particles and for conversion electrons e_k , a system for the time delay between the shutters, and measuring apparatus. The source, deposited on a thin (5μ) aluminum foil, was placed between two modulating resonators. A magnetic-sector β -spectrometer with double focusing, having a momentum resolution of 0.75%, was tuned to the peak of the conversion line. When microwave modulation is switched on, the energy of the e_k passing through the resonator gap changes as a function of the microwave phase. As a result, the β -spectrometer detector registers only those e_k that have not changed their energy, i.e., have passed through the resonator gap at phases 0, π , 2π , etc. As the temporal shutter for α -particles, another resonator is used, which modulates the energy of secondary-emission electrons formed by α -particles when passing through the foil and accelerated in the gap between the foil and the resonator to ~ 2 keV. After passing through the resonator, the electrons are analyzed by energy by means of an electrostatic analyzer and an open-type electron multiplier.

Fig. 1. Block diagram of the apparatus

In Fig. 2 is shown the action of microwave modulation on the energy spectrum of accelerated secondary electrons. Both resonators are powered by a common magnetron generator operating at a frequency of 3 GHz.

For the case of two temporal shutters, between which a variable phase shift φ is introduced, in the presence of a time correlation in the emission of two particles α, e_k , one can obtain an expression for the curve of delayed coincidences—

falling within $N_{\omega\tau}(\varphi)$ in the form

$$N_{\omega\tau}(\varphi) = \frac{1}{\pi} \left\{ 1 + 2 \sum_{k=1}^{\infty} \frac{\exp(-2k^2 R_{\varphi}^2 / a^2)}{[1 + 4k^2 (\omega\tau)^2]} (\cos 2k\varphi + 2k\omega\tau \sin 2k\varphi) \right\}, \quad (1)$$

where ω is the angular frequency; τ is the mean lifetime of the excited state of the nucleus; R_{φ} is the phase resolution, i.e., the half-height width of the prompt-coincidence curve $N_0(\varphi)$, taken in the form of a Gaussian distribution; $a = 2.36$. As $\omega\tau \rightarrow 0$, $N_{\omega\tau}(\varphi)$ goes over into $N_0(\varphi)$, the prompt-coincidence curve. Thus, in the microwave method the prompt-coincidence curve can be obtained not only with the aid of an experiment using an instantaneously decaying source ($\tau \rightarrow 0$), but also on the source under study, with low-frequency modulation of the same amplitude ($\omega \rightarrow 0$).

Fig. 2. Effect of microwave modulation on the energy spectrum of accelerated secondary electrons. *a*—spectrum without modulation, *b*—spectrum with modulation switched on.

For the lifetime measurement, the 269-keV level of Rn^{219} , produced in the α -decay of Ra^{223} , and the 350-keV level of Tl^{207} , produced in the α -decay of Bi^{211} , were selected. These isotopes are members of the actinium series. Sources of Ra^{223} in radioactive equilibrium with the daughter products, with an activity of $1\text{--}2\ \mu\text{C}$, were used. In measuring the lifetime of the 269-keV level of Rn^{219} , the β -spectrometer was tuned to the peak of the *K*-line with energy 171 keV. The half-height line width was $W = 3.5$ keV, and the modulation amplitude was $\mathcal{E}_m = 6.5$ keV.

In Fig. 3 the dependence is shown of the counting rate of α -particle coincidences with e_K on the phase difference between the resonators. The time scale is readily calibrated from the frequency of the microwave generator. The prompt-coincidence curve (curve *a*), obtained by low-frequency modulation, is plotted in the same figure. The half-height width of the curve corresponds to a time resolution of $4 \cdot 10^{-11}$ sec. From this curve the background level is determined, caused by “tails” from conversion lines of higher energy, which create a pedestal for the line under study. Through the experimental points a calculated curve of delayed coincidences (curve *b*) has been drawn, which

Fig. 3. Dependence of the number of α - e_K coincidences on the difference of the microwave phases at the resonators. *a*—prompt-coincidence curve obtained with low-frequency modulation; *b*—delayed-coincidence curve obtained by the delayed-coincidence method; *v*—prompt-coincidence curve obtained with harmonic analysis.

was obtained from formula (1). The prompt-coincidence curve was also found by means of harmonic analysis (curve 6). The lifetime of the level was determined from the slope of the exponential part of the delayed-coincidence curve by comparison with theoretical curves calculated from formula (1), using harmonic analysis. As a result it was found that the half-life of the level is $T_{1/2} = (27 \pm 3)$ nsec. The magnitude of the measurement error is due mainly to the error in determining the background. In comparison with single-particle estimates, the $M1$ transition from the 269-keV level to the ground state is hindered by a factor of 50, whereas the $E2$ transition is accelerated by a factor of 27 for a multipole-mixing ratio $\delta^2 = 0.08$. If the states considered are interpreted as Nilsson states $5/2 + [633]$ and $3/2 + [631]$, then the $M1$ transition agrees with the Nilsson calculation, while the $E2$ transition is accelerated by a factor of 90. These results are typical for weakly deformed nuclei.

In measuring the lifetime of the 350-keV level, the Tl^{207} β -spectrometer was tuned to the corresponding K -line. In this case the accuracy of the measurement is somewhat worse because of a small admixture of M -lines of the 260-keV transition in Rn^{219} . The mean lifetime obtained for the level, $\tau = (4.3 \pm 1.0) \cdot 10^{-11}$ sec, is two times smaller than the limiting estimate given in work (5). The nucleus Tl^{207} has one proton fewer than the doubly magic Pb^{208} . According to the shell model, spins $3/2+$ and $1/2+$ are assigned to the first excited and ground levels of Tl^{207} , and they are identified as single-particle states $2d^{3/2}$ and $3s^{1/2}$. Levels $3/2+$ and $1/2+$ are also observed in other odd thallium isotopes. It is known that in the shell model $M1$ transitions in which the orbital quantum number changes by two units are forbidden.

Relative to single-particle estimates, the $M1$ transition in Tl^{207} is hindered by a factor of 73, while the $E2$ transition is accelerated by a factor of 2.7. A calculation of the probabilities of $M1$ transitions in odd thallium isotopes ($A = 201 \div 203$), performed within the framework of the interacting-quasiparticle model under the assumption of a purely one-quasiparticle transition, gave a large discrepancy with experiment (6). However, a similar calculation for Tl^{207} reveals good agreement with the results of the present experiment. Apparently, the transition $3/2+ \rightarrow 1/2+$ in Tl^{207} is single-particle, whereas analogous transitions in other thallium isotopes have a phonon nature.

The authors thank B. V. Grigor'ev, A. K. Lebedev, and V. A. Smirnov for assistance in the work, and A. I. Egorov and L. M. Vasil'eva for preparing the sources.

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Received 25 VIII 1969

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