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

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Abstract

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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 (5 μ) 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

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

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 $\omega\tau \to 0$, $N_{\omega\tau}(\varphi)$ 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 ($\tau \to 0$), but also on the source under study, with low-frequency modulation of the same amplitude ($\omega \to 0$).

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 1–2 μC, 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 ${}^3/_2+ \to {}^1/_2+$ in Tl^{207} is single-particle, whereas analogous transitions in other thallium isotopes have a phonon nature.

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