Lifetime of the 247-kev Excited State of Cd^{111}†*

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It is shown that lifetime measurements of excited nuclear states may be influenced by extranuclear effects. By a proper choice of the chemical and physical form of the radioactive source this effect can be practically eliminated. Considering this extranuclear perturbation the lifetime of the 247-kev state of Cd^{111} has been determined as $\tau_N=(122.3_{-0.8}{}^{+1.2})$ millimicroseconds. Experimental evidence of the influence of extranuclear effects on lifetime measurements is presented.

1. INTRODUCTION

THE lifetime of the 247-kev excited state of Cd^{111} plays an important role in the evaluation and interpretation of directional correlation measurements on the Cd^{111} gamma cascade which involve this state as an intermediate step.[1] The first delayed-coincidence measurements indicated that the lifetime of this state must be between 110 mμsec[2,3] and 140 mμsec.[4] No precise value of this lifetime, however, was available at the time this investigation was started (1953). The value of the mean life, $\tau_N=(124\pm6)$ mμsec, which is generally quoted in the directional-correlation literature was extracted from unpublished measurements performed in this laboratory in 1950.[5] The accuracy of nuclear data obtained on the basis of observations of extranuclear effects on angular correlations is strongly affected by the large error of this early lifetime determination. Thus it was decided to remeasure the lifetime of the first excited Cd^{111} state with improved techniques and apparatus. The investigation presented in this paper yields the following values for the mean life τ_N and the half-life $T_{\frac{1}{2}}$ of the 247-kev excited state of Cd^{111}, $\tau_N=(122.3_{-0.8}{}^{+1.2})$ mμsec and $T_{\frac{1}{2}}=(84.8_{-0.5}{}^{+0.8})$ mμsec, respectively. After completion of our investigation two other determinations of the lifetime of the Cd^{111} state were reported. Rietjens *et al.*[6] found a value of $\tau_N=(123\pm3)$ mμsec, whereas Maier and Meyer[7] computed the precise value of $\tau_N=(121.3\pm0.7)$ mμsec from their delayed-coincidence experiments with the conversion electrons which are emitted in the de-excitation of the Cd^{111} state. The agreement of the two values with the result of our measurements is satisfactory.

2. EFFECTS OF PERTURBED DIRECTIONAL CORRELATIONS ON LIFETIME MEASUREMENTS

In most cases, lifetime measurements of excited states involve observations of delayed coincidences between the radiations preceding the formation of the excited state and the radiation emitted from this state. The propagation directions, however, of the two radiations are, in general, not independent from each other, but exhibit a directional correlation, $W(\theta)$. Furthermore, this directional correlation may be influenced by the interactions of extranuclear fields with the nuclear moments of the state whose mean life τ_N is to be measured. The degree to which this interaction affects the correlation is dependent upon the time t during which the nuclear state is exposed to the interaction. Thus $W(\theta)$ is also a function of t: $W(\theta,t)$. An introduction of a delay t into one channel of the coincidence arrangement affects the coincidence counting rate not only by virtue of the decay (e^{-t/τ_N}) of the excited state but also by virtue of the time dependence of $W(\theta,t)$. As a matter of fact, just in those cases where τ_N is of such a magnitude that it can be measured by the delayed-coincidence method, the directional correlation is expected to be disturbed.

The unperturbed directional correlation is of the form[8]

$$W(\theta)=1+\sum_{k=1}^{k_{\max}} A_{2k}{}^0 P_{2k}(\cos\theta). \quad (1)$$

The presence of a perturbing interaction in a source, which as a whole has an isotropic structure, results in a simple modification of the directional correlation[9]:

$$W(\theta,t)=1+\sum_{k=1}^{k_{\max}} G_{2k}(t) A_{2k}{}^0 P_{2k}(\cos\theta), \quad (2)$$

where the attenuation coefficients $G_{2k}(t)$ depend upon the parameters which describe the extranuclear interaction ($|G_{2k}(t)|\leq 1$). For static interactions the $G_{2k}(t)$ are periodic functions of t involving a "precession frequency" ω_0. Time-dependent interactions are charac-

† A brief account of this work has been presented at the spring meeting of the American Physical Society at Washington, D. C., April 26–28, 1956 [P. C. Simms and R. M. Steffen, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956)].

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[5] See, e.g., H. Aeppli *et al.*, Helv. Phys. Acta 25, 339 (1952).
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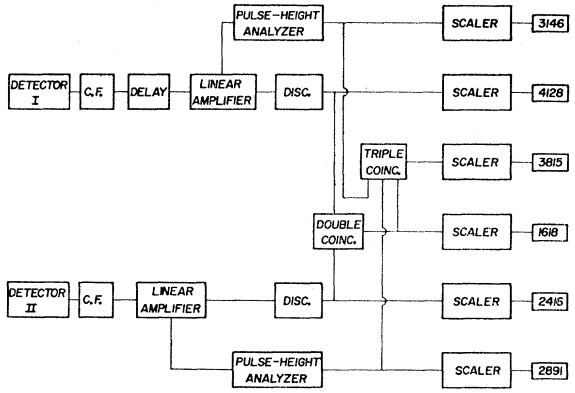

FIG. 1. Block diagram of coincidence analyzer.

terized by exponential functions $G_{2k}(t)=e^{-\lambda_{2k}t}$, where the λ_{2k} are a kind of relaxation parameters. The number of "delayed coincidences" observed with a coincidence analyzer whose "prompt coincidence" resolution curve is given by $P(t')$ and whose channel detecting the first radiation incorporates a delay T, can be expressed by the following integral:

$$C(\theta_0,T)=\text{const}\int_0^{+\infty}P(T-t)e^{-t/\tau_N}\times\left[1+\sum_{k=1}^{k_{\max}}Q_{2k}G_{2k}(t)A_{2k}{}^0P_{2k}(\cos\theta_0)\right]dt. \quad (3)$$

The factor Q_{2k} takes into account the corrections for finite angular resolution of the two detectors whose axes subtend an angle of θ_0 at the source.[10,11]

In order to simplify the discussion of this equation, let us assume a rectangular "prompt coincidence" resolution curve $P(t')$:

$$\begin{aligned}&P(t')=1 \quad \text{for} \quad \tau_0\geq t'\geq-\tau_0,\\ &P(t')=0 \quad \text{for} \quad t'>\tau_0 \quad \text{and} \quad t'<-\tau_0.\end{aligned} \quad (4)$$

Equation (3) reduces then to

$$C(\theta_0,T)=\text{const}\int_{T-\tau_0}^{T+\tau_0}e^{-t/\tau_N}\times[1+G_{2k}(t)Q_{2k}A_{2k}{}^0P_{2k}(\cos\theta_0)]dt, \quad (5)$$

or

$$C(\theta_0,T)=\text{const}\left[1+\sum_{k=1}^{k_{\max}}\tilde{G}_{2k}(T)\times Q_{2k}A_{2k}{}^0P_{2k}(\cos\theta_0)\right]e^{-T/\tau_N} \quad (6)$$

for $T>\tau_0$. Due to the presence of the function $\tilde{G}_{2k}(T)$, whose form depends on the extranuclear interaction, the decrease of the coincidence counting rate as a function of the delay time T is not a simple exponential function. In order to extract the value of τ_N from a delayed-coincidence curve, either the functions $\tilde{G}_{2k}(T)$ must be known from other experimental data or the experiment must be designed in such a way as to make the second term in the square bracket of Eq. (6) independent of T. The latter is true if one or more of the following conditions are satisfied:

1. $A_{2k}{}^0=0$ for all k, case of isotropic correlation.
2. $\tilde{G}_{2k}(T)\ll1$ for all values of $T>\tau_0$, case of strong nonstatic interaction ($\tau_N\lambda_{2k}\gg1$, $\tau_0\lambda_{2k}\gg1$).
3. $\tilde{G}_{2k}(T)\simeq$const for all values of $T>\tau_0$; (i) case of small interaction ($T\lambda_{2k}\ll1$, $T\omega_0\ll1$), (ii) case of strong static interaction (hard core) ($\tau_N\omega_0\gg1$, $\tau_0\omega_0\gg1$).
4. $Q_{2k}\ll1$, case of poor angular resolution.
5. $P_{2k}=0$ for all k, possible only for $k_{\max}=1$; ($P_2=0$ for $\theta_0=125°\,40'$).

3. EXPERIMENTAL

3.1 Measurements of the Lifetime of the 247-kev State of Cd^{111}

The electronic equipment used for these measurements was of the usual fast-slow type. Its salient features are described elsewhere.[12] The block diagram is shown in Fig. 1. Because of the finite rise time of the pulses arriving at the fast discriminators, the time moment at which the discriminator fires depends upon the pulse size. Large pulses trigger the discriminator earlier than small ones for a given discriminator level

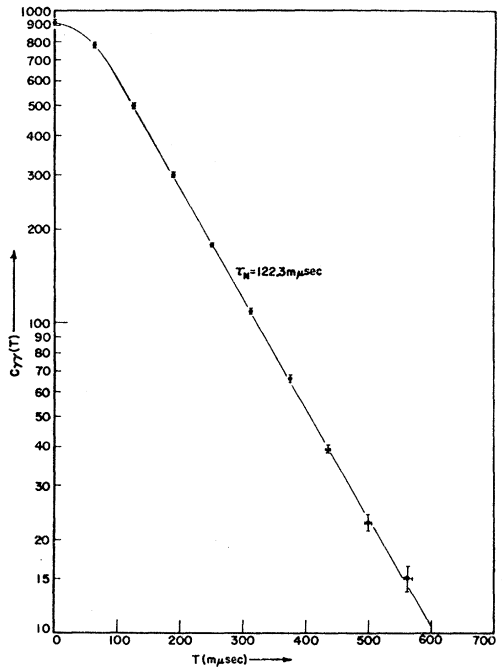

FIG. 2. Typical example of a decay curve of the 247-kev excited state of Cd^{111}.

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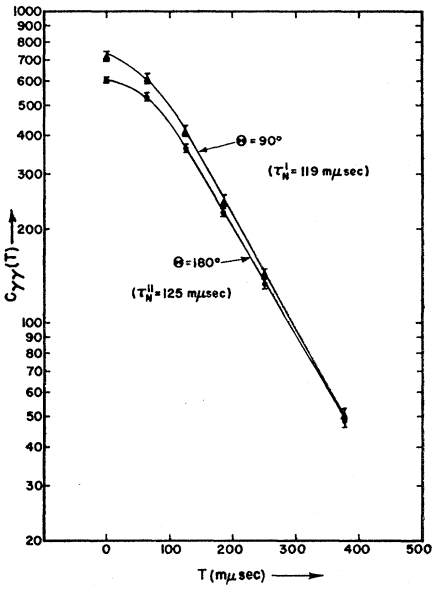

FIG. 3. Decay of the 247-kev excited state of Cd^{111}. The two delay curves were observed at different angles θ with identical viscous sources of In^{111}.

setting. This effect introduces an undesirable additional delay, if the pulses are attenuated in long preceding delay cables. To minimize this effect, the discriminators were set at a very low level and the pulses arriving at the discriminators were adjusted to be of constant amplitude. This was done in the following way: the window width of the single-channel analyzers was made as small as possible and kept at a constant level to accept the photopeak of the $In^{111}-Cd^{111}$ gamma rays without delay cable. The small attenuation ($<3\%$) of the pulses if delay cables were inserted was then compensated by increasing the amplification in the cathode followers until the peak appeared again in the narrow pulse height analyzer window. By using a fast mercury switch pulser a careful check of this procedure revealed that the time uncertainty was less than 0.002 microsecond for delays up to 1.5 microseconds (1200 feet of RG 7/U cable).

The delay cables were calibrated by determining the resonance frequencies with a high-frequency oscillator. It was noted that the couplings between two lengths of cables introduced a small delay, thus care was taken to have always the same number of couplings in both channels. The resolving time of the coincidence system was either 81 mμsec (for 10 runs) or 129 mμsec (for 14 runs). The In^{111} sources, whose preparation is described in reference 12, were either in the form of very dilute aqueous solutions of $InCl_3$ where the time-dependent interaction is very small (condition 3i) or in the form of very viscous glycerine solutions with large time-dependent interactions (condition 2). The sources were placed at a distance of 0.5 cm from the detectors; thus condition 4 was also reasonably well satisfied.

A typical delay curve measured with one of these sources is shown in Fig. 2. Summarizing the results obtained with 24 measurements of this kind gives the following result:

$$\tau_N = (122.3_{-0.8}^{+1.2})\ \text{m}\mu\text{sec},$$

or

$$T_{\frac{1}{2}} = (84.8_{-0.5}^{+0.8})\ \text{m}\mu\text{sec}.$$

The error quoted includes not only the statistical errors, which are very small (0.2%), but also takes into account the error in the delay cable calibration, as well as the error in the timing of the discriminator firing. Thus the error can be considered as the maximum error.

3.2 Influence of Extranuclear Interactions on Lifetime Measurements

In order to verify the existence of the influence of the directional-correlation perturbation on the lifetime measurement, an experimental arrangement of detectors and an In^{111} source were chosen which did not satisfy any of the requirements mentioned in Sec. 2. A viscous solution of $InCl_3$ in water and glycerine, which displayed an undelayed directional correlation of

$$W(\theta) = 1 + (0.12 \pm 0.01) P_2(\cos\theta),$$

was found to be very satisfactory for this purpose. Figure 3 shows the delay curves determined at two angles $\theta_0 = 90°$ and $\theta_0 = 180°$. The "apparent lifetimes", determined from the slopes of the two curves are also indicated. The difference between the two "apparent values" of τ_N is considerable and indicates that care must be exercised in measurements of lifetimes of excited states if the directional correlation between the preceding and following radiation is perturbed by extranuclear effects.

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