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Lifetime Measurements for the First Excited States in ^{107}Cd and ^{105}Cd

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We performed delayed coincidence measurements for the first excited levels of ^{107}Cd and ^{105}Cd and obtained the following results: τ(205 keV, ^{107}Cd) = (1.03 ± 0.05) ns, τ(321 keV, ^{107}Cd) ≤ 60 ps, τ(131 keV, ^{105}Cd) = (2.52 ± 0.15) ns. Experimental results are in agreement with the predictions of the intermediate coupling nuclei.

I. INTRODUCTION

In recent works the decay scheme of ^{107}In feeding the levels of ^{107}Cd has been reported.[1,2] This isotope presents a nearly pure $M1$ transition between the first excited state $\frac{7}{2}^+$(205 keV) and the $\frac{5}{2}^+$(g.s.). The same situation seems to occur in the level schemes of ^{105}Cd fed by the 5-min decay of ^{105}In[3] and of ^{109}Cd in which Ben-Zvi *et al.*[4] measured a hindrance factor of 10 for the $\frac{7}{2}^+$(203.5 keV) → $\frac{5}{2}^+$ (g.s.) predominantly $M1$ transition.[5]

In order to follow the evolution of the transition probabilities, we started lifetime measurements in ^{107,105}Cd and also in ^{109}Cd.

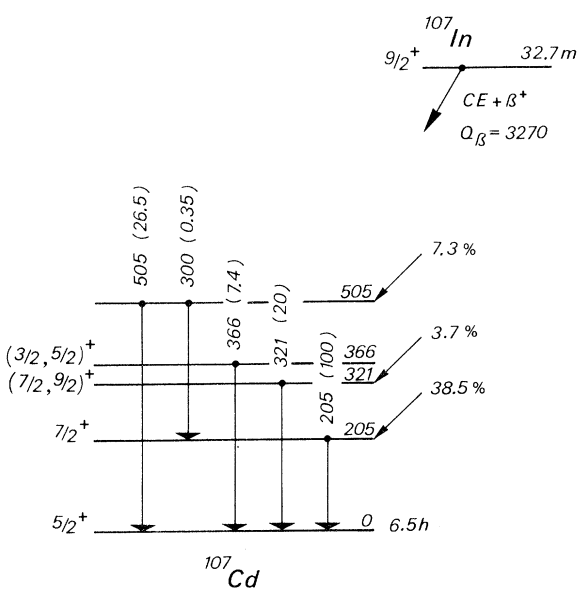

FIG. 1. Partial decay scheme of ^{107}In → ^{107}Cd from Ref. 1.

II. EXPERIMENTAL

A. Source Preparation

The 4.3-h ^{109}In, 32.7-min ^{107}In, and 5.1-min ^{105}In sources were obtained by irradiation of enriched isotopes: 97.2% ^{110}Cd, 82.4% ^{108}Cd, and 88.4% ^{106}Cd, respectively, in the Grenoble isochronous cyclotron with 26-MeV protons. The ^{110}Cd(p, 2n)-^{109}In and ^{108}Cd(p, 2n)^{107}In reactions give pure sources. This point was checked by reference to isotopically separated sources. In the case of ^{105}In production, recent studies[3] showed that 2-min-long irradiations gave ^{105}In sources in which the parasitic activities were without any effect in the energy range of interest (cf. Sec. B 3).

B. Measurements

The lifetime measurements were performed by the delayed coincidence method. We used NE111 plastic and NaI(Tl) scintillators coupled to XP1021 and 2106 photomultipliers.

1. 205-keV First Level in ^{107}Cd

Figure 1 shows the partial decay scheme of ^{107}In → ^{107}Cd.[1] We selected the positrons of energy E_{β^+} > 1940 keV with a thin (8-mm) plastic scintillator and the 205-keV γ rays by means of a 2.5-cm × 2.5-cm plastic scintillator, setting the energy window on the corresponding Compton edge. A 4-mm aluminum absorber was placed in front of the second scintillator to prevent the absorption of positrons in the detector.

In order to avoid the contribution of the positronium lifetime in the plastic, the photomultipliers were placed at 90° and a lead screen was interposed between the two scintillators.[6]

Figure 2 shows the measured delayed curve.

The prompt curve was obtained in the same conditions using a ^{76}As source: the β^- decay (E_{max} = 2460 keV) of ^{76}As fed a 559-keV level in ^{76}Se, the lifetime of which is 12 ps.[7] A least-squares fit treatment of the slope results in τ(205 keV, ^{107}Cd) = 1.03 ± 0.05 ns.

2. 321-keV Second Level in ^{107}Cd

We selected positrons of energy in the range $1750 \leq E_{\beta^+} \leq 1930$ keV and the Compton edge of 321-keV γ radiations (Fig. 1). The measurement was performed by comparing the centroid of the time correlation curve with that of an ^{76}As source. The two sources of same intensity were interchanged every twenty min. We deduced the following upper limit: τ(321 keV, ^{107}Cd) ≤ 60 ps.

3. 131-keV First Level in ^{105}Cd

Figure 3 shows a partial level scheme of ^{105}Cd fed by 5.1-min ^{105}In.[3] The 131-keV γ rays were selected with a NaI(Tl) crystal and the Compton edge of (639 + 668 + 700 keV) γ radiations with a plastic scintillator. Because of the shortness of the source lifetime, the measurements started 1 min after the end of 2-min-long irradiations and lasted 10 min. A contribution of prompt events due to the Compton of higher energy is present on the experimental result (Fig. 4). The slope of this experimental result was fitted with a least-squares treatment and led to the lifetime

$$\tau(131 \text{ keV}, {}^{105}\text{Cd}) = (2.52 \pm 0.15) \text{ ns}.$$

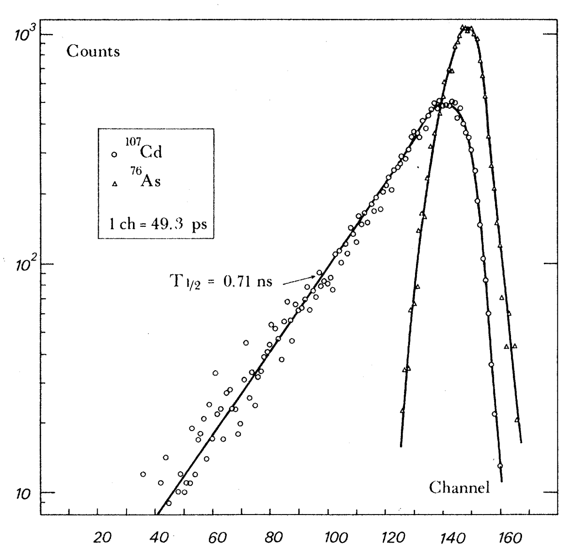

FIG. 2. Time correlation curve between β^+ and the 205-keV γ ray in ^{107}Cd. The ^{76}As prompt curve was obtained with the same energy settings.

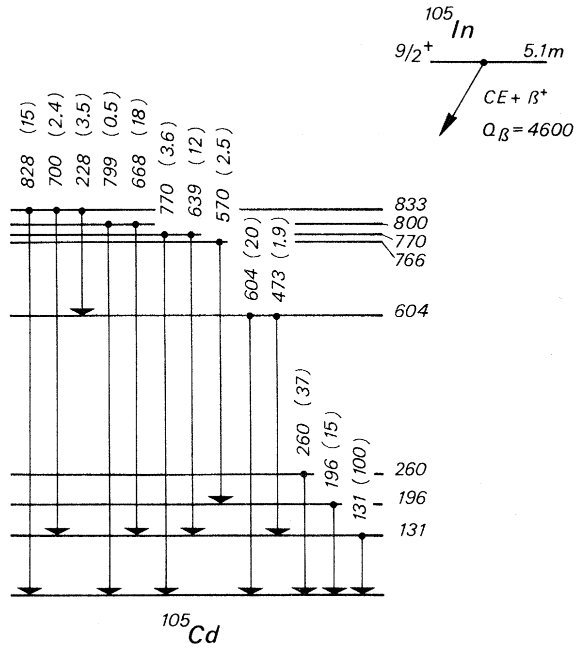

FIG. 3. Partial decay scheme of ^{105}In → ^{105}Cd.

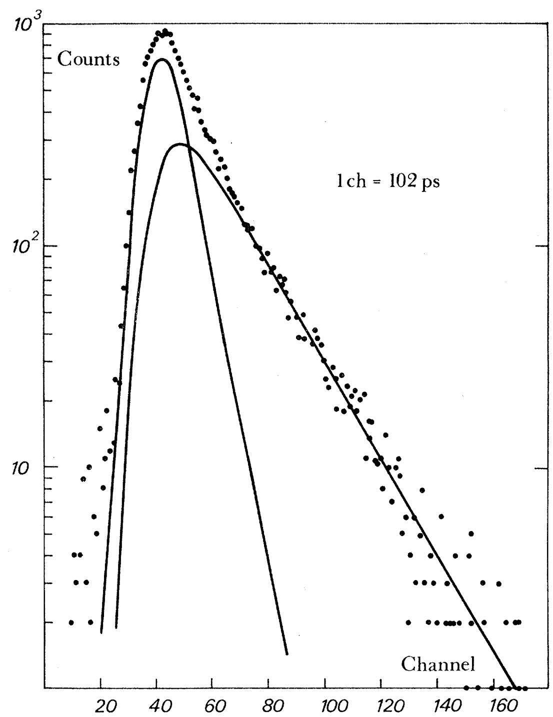

FIG. 4. Time correlation curve between the 600- and 131-keV γ rays in ^{105}Cd. The theoretical delayed curve fitted on the slope of the experimental one and the contribution of prompt events are shown as continuous curves.

TABLE I. Comparison between calculated and experimental electromagnetic properties in ^{105,107,109}Cd. Th. 1: $g_{s\,\mathrm{eff}}$ is chosen in order to reproduce the $\mu_{5/2}$ experimental value. Th. 2: the tensor term $\langle g_s' \rangle = 0.75$ is taken into account in the effective $M1$ operator. For ^{105}Cd we used the same wave functions as for ^{107}Cd. Experimental data are taken from Refs. 1, 4, 5, 17, and 18 as indicated.

		Th. 1	Th. 2	Exp	Ref.
$\mu_{\frac{5}{2}_1}$ (μ_N)	^{105}Cd	−0.74	−0.74	−0.7385 ± 0.0002	18
	^{107}Cd	−0.62	−0.62	−0.616 ± 0.015	17
	^{109}Cd	−0.83	−0.83	−0.839 ± 0.015	17
$B(M1\,\frac{7}{2}_1 \to \frac{5}{2}_1)$ $(\mu_N{}^2)$	^{105}Cd	1.4×10^{-3}	8×10^{-3}	$(7.9\pm0.5)\times10^{-3}$	
	^{107}Cd	1×10^{-3}	6×10^{-3}	$(6.0\pm0.3)\times10^{-3}$	
	^{109}Cd	0.85×10^{-3}	0.8×10^{-2}	0.13 ± 0.02	4
$\delta^2(\frac{7}{2}_1 \to \frac{5}{2}_1)$	^{107}Cd	2.4×10^{-2}	5×10^{-3}	predominantly $M1$	1
	^{109}Cd	3×10^{-2}	2.6×10^{-3}	predominantly $M1$	5
$Q_{\frac{5}{2}_1}$ $(e\,\mathrm{b})$	^{107}Cd	0.84	···	0.8 ± 0.1	17
	^{109}Cd	0.73	···	0.78 ± 0.1	17

4 205-keV Second Excited Level in ^{109}Cd

Using the same apparatus, we studied the $\frac{7}{2}^+$ (203.5 keV) excited state in ^{109}Cd. By comparison with a prompt curve given by the ^{76}As source, we deduced the limit $\tau(203.5\text{ keV},\ ^{109}\text{Cd}) \le 60$ ps in agreement with the value of Ben-Zvi *et al.*[4]: $\tau = 52^{+9}_{-6}$ ps obtained by the microwave method.

5. Transition Probabilities

In ^{107}Cd and ^{109}Cd the values of K/L ratios[1,5] imply predominantly $M1$ transitions for $\frac{7}{2} \to \frac{5}{2}$. But no definitive values of $\delta^2(E2/M1)$ are available up to now and weak $E2$ admixtures are not completely excluded. Nevertheless in ^{107}Cd we can derive the maximum reduced transition probability $B(M1) = [(0.60\pm0.03)\times10^{-2}]\mu_N{}^2$ and the hindrance factor $B_{\mathrm{Weisskopf}}(M1)/B_{\mathrm{exp}}(M1) = 207$. The hindrance factor determined by Ben-Zvi *et al.*[4] for the analog $(\frac{7}{2}^+ \to \frac{5}{2}^+)\,M1$ transition in ^{109}Cd is only 10.

The spin and parity of the first excited state of ^{105}Cd is assumed to be $\frac{7}{2}^+$.[3] In this case the 131-keV transition may have a predominantly $M1$ character. The reduced transition probability becomes $B(M1) = [(0.79\pm0.05)\times10^{-2}]\mu_N{}^2$ and the hindrance factor $B_W(M1)/B_{\mathrm{exp}}(M1) = 156$.

III. DISCUSSION

The calculations of Kisslinger-Sorensen ($P + QQ$ model)[8] and Bês-Dussel (anharmonic approach)[9] reproduce fairly well most of the properties of the heaviest Cd isotopes. Unfortunately, no prediction concerning $M1$ transition probabilities is available up to now in the light Cd isotopes. Therefore, we attempt to describe in the framework of the intermediate coupling model the ^{107}Cd and ^{109}Cd nuclei as a quasiparticle of a neutron coupled to the ^{106}Cd and ^{108}Cd core, respectively. The quasiparticle orbits chosen are $2d^{5/2}$, $1g^{7/2}$, $2d^{3/2}$, $3s^{1/2}$, and their corresponding nonoccupation amplitudes U_j are taken from (d,p) reaction data.[10] We deduced the core matrix elements from the observed transition rates and quadrupole moments of the cores ^{106}Cd and ^{108}Cd.[11,12] Our approach is similar to calculations carried out for the odd cobalt isotopes by Stewart, Castel, and Singh.[13]

For the best fit obtained in $^{107-109}$Cd between experimental and theoretical spectra, it is worth noting that, for the ground state $\frac{5}{2}^+$ and first excited state $\frac{7}{2}^+$, the most important components in their wave functions are of pure quasiparticle nature; for ^{107}Cd, we obtained the following wave functions (neglecting small components <4%):

$$|\tfrac{5}{2}{}_1^+\rangle = 0.80|\tfrac{5}{2},\ 0\ 0;\ \tfrac{5}{2}\rangle + 0.53|\tfrac{5}{2},\ 1\ 2;\ \tfrac{5}{2}\rangle + \cdots$$

$$|\tfrac{7}{2}{}_1^+\rangle = -0.84|\tfrac{7}{2},\ 0\ 0;\ \tfrac{7}{2}\rangle + 0.47|\tfrac{7}{2},\ 1\ 2;\ \tfrac{7}{2}\rangle - 0.25|\tfrac{3}{2},\ 1\ 2;\ \tfrac{7}{2}\rangle + \cdots .$$

We calculated the electromagnetic properties and compared them to experimental results in Table I. It can be seen that the $B(M1)$ calculated values are in good agreement (except for ^{109}Cd) with the experimental ones, especially when we include in the effective magnetic operator the tensor term $g_s'(r)|Y_2\times s|_1^{\mu}$.[14] It has been shown[15,16] that its effect is generally important in $\Delta l = 2$ forbidden $M1$ transitions.

More experiments on these magnetic properties are needed in similar nuclei (Pd, Ru) to follow the $M1$ neutron hindrance factor.

[1]J. Rivier and R. Moret, Nucl. Phys. A177, 379 (1971).
[2]G. D. Dracoulis, W. Gelletly, R. Chapman, J. N. Mo, and A. J. Hartley, Particles and Nuclei, 4, 43 (1972).
[3]J. Rivier and R. Moret, Radiochim. Acta (to be published).
[4]I. Ben-Zvi, A. E. Blaugrund, Y. Dar, G. Goldring, and Y. Wolfson, Nucl. Phys. A135, 153 (1969).
[5]M. Nozawa, Nucl. Phys. 37, 411 (1962).
[6]R. Béraud, I. Berkes, M. Lévy, G. Marest, and R. Rougny, Nucl. Phys. A99, 577 (1967).
[7]*Nuclear Data Sheets 1959–1965,* compiled by the Nuclear Data Group (Academic, New York, 1966).
[8]L. S. Kisslinger and R. A. Sorensen, Rev. Mod. Phys. 35, 853 (1963).
[9]R. D. Bès and G. G. Dussel, Nucl. Phys. A135, 1 (1969).
[10]V. D. Mistry, C. L. Hollas, H. R. Hiddleston, and P. J. Riley, Phys. Rev. C 1, 1595 (1970).
[11]G. Schilling, R. P. Scharenberg, and J. W. Tippie, Phys. Rev. C 1, 1400 (1970).
[12]W. T. Milner, F. K. McGowan, P. H. Stelson, R. L. Robinson and R. O. Sayer, Nucl. Phys. A129, 687 (1970).
[13]K. W. C. Stewart, B. Castel, and B. P. Singh, Phys. Rev. C 4, 2131 (1971).
[14]A. Bohr and B. R. Mottelson, *Nuclear Structure* (Benjamin, New York, 1969), Vol. 1, pp. 336–344.
[15]K. H. Maier, K. Nakai, J. R. Leigh, R. M. Diamond, and F. S. Stephens, Annual Report of Berkeley Laboratory, 1972 (unpublished), p. 10.
[16]A. Arima, in *Proceedings of the International Conference on Nuclear Moments and Nuclear Structure, 1972, Osaka,* edited by H. Horie and K. Sugimoto (Physical Society of Japan, 1973), p. 205.
[17]M. N. McDermott and R. Novick, Phys. Rev. 131, 707 (1963).
[18]N. S. Laulainen and M. N. McDermott, Phys. Rev. 177, 1615 (1969).