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Absolute E1 and E2 transition rates in ^{110}Cd

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Abstract. The lifetimes of several states in ^{110}Cd have been determined by means of the generalized centroid-shift method. The reaction ^{108}Pd(α,2n) has been used and the following results were obtained: $T_{1/2}$(2879 keV) = 0.60 ± 0.10 ns, $T_{1/2}$(3029 keV) = 0.30 ± 0.10 ns, $T_{1/2}$(3056 keV) = 2.25 ± 0.10 ns, $T_{1/2}$(3611 keV) = 0.45 ± 0.10 ns. Electric dipole and quadrupole transitions are discussed in terms of octupole and quadrupole collectivity. The odd-spin sequence of the semi-aligned structure $\nu(h_{11/2}d_{5/2})$ has been established with the band-head at $J^\pi = 7^-_2$ identified as a new two-quasiparticle isomer, the lower-lying $5^-_{1,2}$ states being of two-quasiproton character.

Nuclear Reaction: ^{108}Pd(α,2n), E = 27 MeV,; measured E_γ, I_γ, γ-r.f. Deduced: $T_{1/2}$, B(αL) in ^{110}Cd. Ge detectors. Generalized centroid-shift analysis.

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1 Introduction

With two proton holes away from the Z = 50 shell, as well as a small and soft β_2 deformation, the even-mass Cd nuclei with N ≤ 66 offer a very good opportunity to obtain interesting information about the competition between rotational and vibrational structures. In addition, intrinsic excitations appear close to the yrast line. Therefore, the Cd isotopes have been a subject of many detailed experimental and theoretical investigations (e.g. [1–8] and refs. therein).

The absolute electromagnetic transition probabilities are one of the most powerful tools to get information on the structure of the states involved. With the (sub)nanosecond lifetime measurements performed in [9–11] we initiated a systematic study of absolute transition rates in even-mass Pd and Cd nuclei. They revealed for the first time the existence of semi-decoupled rotational bands in the A ≈ 100 mass-region. Moreover, we were able to localize two-quasiproton 8^+ yrast configurations in $^{104-108}$Cd [10].

The level scheme of ^{110}Cd as thoroughly investigated by J. Kern et al. [5] in their (α,2n) study revealed the possibility to extend this systematics to ^{110}Cd. With this aim, we carried out delayed γ-r.f. coincidences at the Rossendorf cyclotron U − 120 using the same reaction.

During the course of the present study, extensive experimental results on band structures and lifetimes of excited states in ^{110}Cd from (HI,xn) investigations have been published [1, 2]. They include the lifetimes of three out of four isomers found in our experiments.

2 Experimental procedure

Excited states in ^{110}Cd were populated in the ^{108}Pd(α,2n) reaction using 27 MeV α-particles. The metallic powder ^{108}Pd target with a thickness of about 20 mg/cm^2 and an enrichment of 98% was deposited on a polyester foil.

The timing measurements were performed by means of the delayed γ-r.f. coincidence method (see e.g. [11]). The pulses from a 1 cm^3 planar Ge(Li) detector provided the start signals for the time-to-amplitude converter. The stop signals were derived from the cyclotron oscillator. The overall time resolution of the experimental set-up was FWHM ≈ 6 ns. The data were recorded on-line in a energy (4096 channels) x time (256 channels) matrix. Setting cuts on the time axis as well as on the energy axis of the matrix, delayed γ-ray spectra and time distributions, respectively, were sorted out off-line. Thereby, the time distributions of all γ-ray transitions of interest and neighbouring background regions were created. Further, these time distributions have been analyzed according to the generalized centroid-shift method [11, 12]. Net time distributions (time centroids) are produced after subtracting background contributions beneath the peak and random

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coincidences. In a centroid diagram the time centroids are plotted versus γ-ray energies. Deviations from the zero-time line indicate measurable lifetimes. This line is ascertained by a numerical fit of the time centroids of prompt transitions.

3 Experimental results

The centroid diagram obtained in the ^{108}Pd(α,2n)^{110}Cd reaction is displayed in Fig. 1 while a partial level scheme according to [1, 5] and the present work is shown in Fig. 2.

The 10^+ level at 3611 keV is deexcited by the 171, 265, 336 and 424 keV transitions (Fig. 2). In our measurements, the 171 keV transition forms an unresolved doublet with a transition belonging to ^{110}Cd while the 424 keV one is too weak to be used in the analysis. We evaluated the time centroids obtained for the 265 and 336 keV transitions (Fig. 1) and determined an average value of

$$\mathrm{T}_{1/2}(10^+, 3611\mathrm{keV}) = 0.45 \pm 0.10\mathrm{ns},$$

which agrees very well with that obtained by S. Juutinen et al. [1] amounting to 0.49(0.14) ns.

The 160 and 177 keV transitions depopulate the 8_1^- level at 3056 keV (Fig. 2). The centroid positions observed for both transitions show large deviations from the zero-line (Fig. 1), which correspond to a half-life of

$$\mathrm{T}_{1/2}(8_1^-, 3056\mathrm{keV}) = 2.25 \pm 0.10\mathrm{ns}.$$

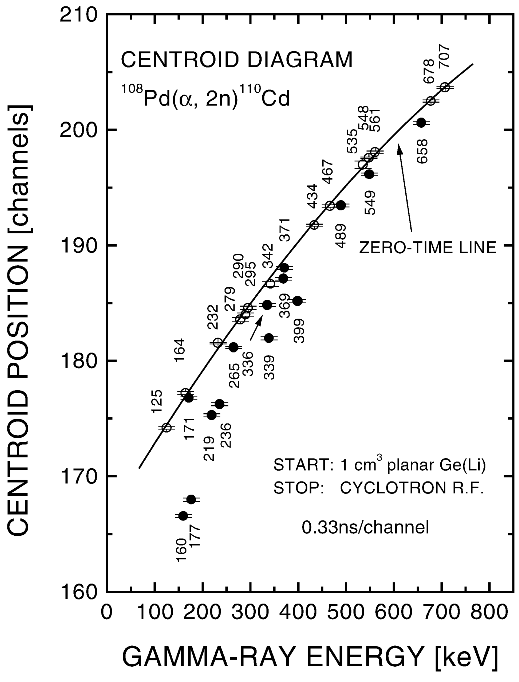

Fig. 1. Centroid positions of some of the time distributions obtained in the ^{108}Pd(α,2n)^{110}Cd reaction. The time centroids are labelled with the transition γ-ray energies in keV. The time centroids used for the determination of the zero-time line are denoted by open circles

Within error bars this result is in agreement with that published in [1] ($\mathrm{T}_{1/2}$ = 2.42(35) ns).

The 7_1^- level at 2879 keV is deexcited by the 219, 339 and 399 keV transitions (Fig. 2). The centroid shifts from the zero-time line measured for all these transitions are nearly equal (Fig. 1). Taking into account the delayed feeding from the 8_1^- level at 3056 keV level we derived a half-life of

$$\mathrm{T}_{1/2}(7_1^-, 2879\mathrm{keV}) = 0.60 \pm 0.10\mathrm{ns}.$$

Again, very good agreement is observed between our result and that of Juutinen et al. [1] ($\mathrm{T}_{1/2}$ = 0.62(14) ns).

The 150, 369, 489 and 549 keV transitions deexcite the 7_2^- state at 3029 keV (Fig. 2). The first one (149.9 kev) appears as a doublet in the γ-ray spectrum with the 150.6 keV transition in ^{111}Cd and was not considered in the analysis. As can be seen from Fig. 1, the other three transitions are delayed. At this point, we note that very close to the 369 and 549 keV transitions are present the prompt 371 and 548 keV ones, respectively. The 371 and 548 keV transitions deexcite the 8_2^- level at 3428 keV (not shown in Fig. 2) for which Piiparinen et al. [2] determined a lifetime of 8.6 ps in their recoil-distance experiments. In this way, the centroid positions of the neighbouring transitions can be directly compared (Fig. 1) and the isomeric character of the level considered seems convincingly revealed. Evaluating the centroid shifts corresponding to the 369, 489 and 549 keV transitions we determine a half-life of

$$T_{1/2}/(7_2^-, 3029keV) = 0.30 \pm 0.10ns.$$

At this point, we want to exclude a hypothetical possibility which could lead to an erroneous conclusion about the half-life of the 7_2^- state: An unobserved low-energy (27 keV) weak (with an intensity only about 10the 8_1^- (at 3056 keV) and 7_2^- (at 3029 keV) levels (s. Fig. 2) would cause such an isomeric behaviour (effective lifetime) of the 7_2^- state. Indeed, as discuss below, the 8_1^-–10_1^-–12_1^- etc. and 7_2^-–9_2^-–11_2^- etc. sequences represent the signature partners mainly built on the n($h_{11/2}d_{5/2}$) configuration. However, in the investigations performed so far, only transitions from the odd-spin states to even spin ones have been observed and not vice versa (s. also Fig. 2). Moreover, if the 3056 and 3029 keV levels would be connected by a 27 keV transition, the whole cascade of transitions deexciting the 3029 keV should be in coincidence with the 1107.0 keV transition, which is obviously not the case according to Fig. 2b of [1]. Therefore, we conclude that the 0.3 ns half-life can be assigned unambiguously to the 7_2^- level at 3029 keV. The deviations from the zero-time line observed for the centroid positions of the 236 and 658 keV transitions are due to delayed feeding from the above discussed levels.

4 Discussion

4.1 General remarks

The absolute transition probabilities derived from the lifetimes measured in the present work are summarized in

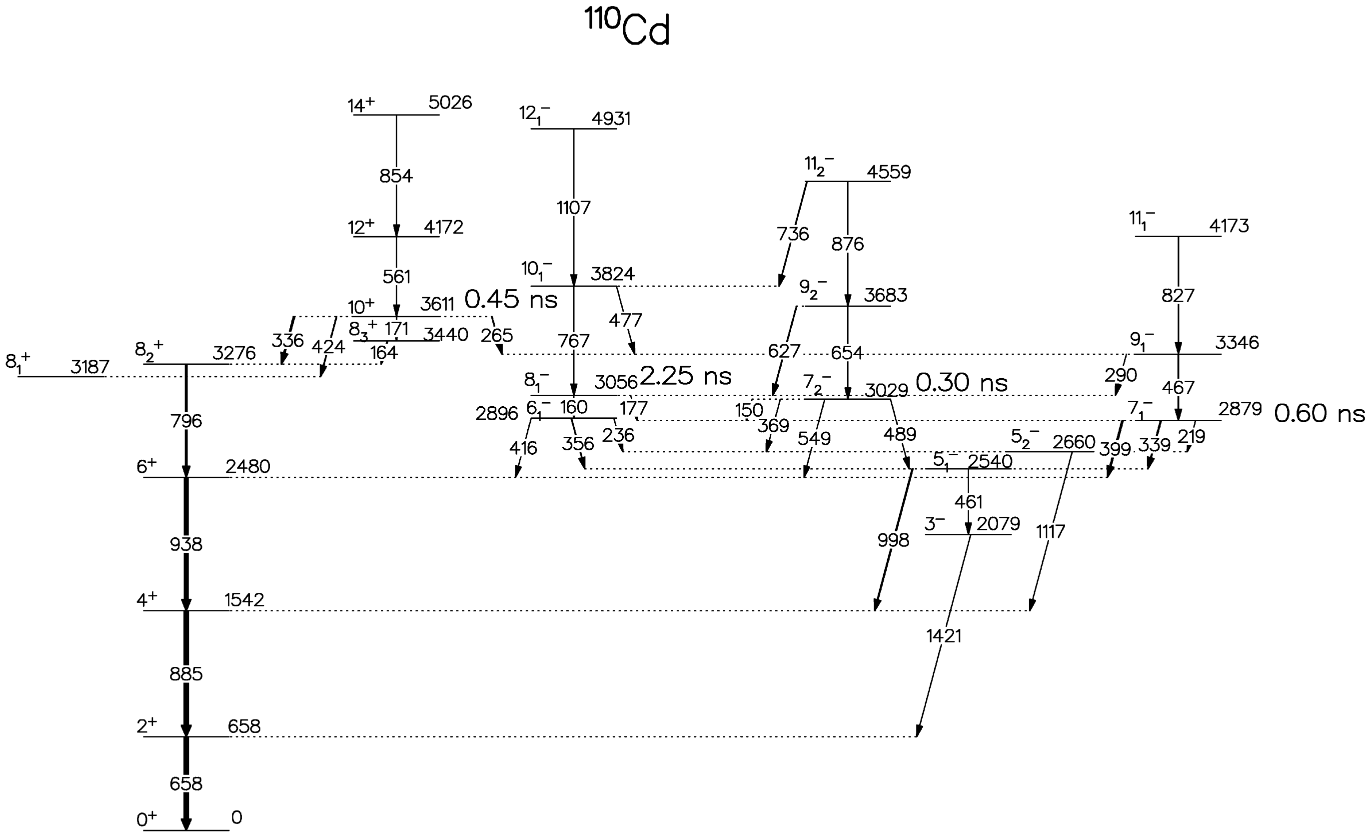

Fig. 2. Partial level scheme of ^{110}Cd according to [1, 5] and the present work. The half-lives were determined in the present investigations

Table 1. Thereby, γ-ray intensities from our experiments as well as from [1, 5] and conversion coefficients calculated by means of the tables in [13] have been used.

We consider the value B(E2, $2_1^+ \Rightarrow 0^+$) = 23 W.u. in ^{110}Cd [2] as a measure for the quadrupole collectivity in this nucleus while the value B(E1, $3_1^- \Rightarrow 2_1^+$) = 1.4×10^{-4} W.u. known in ^{106}Pd [14] has been used as representative for the octupole E1 transition strength in this mass region. Below, we compare the E1 and E2 transition rates determined in our investigations with these values. The comparison facilitates the conclusions on the two-quasiparticle character and the collectivity of nuclear levels and transitions.

We discuss the two-quasiparticle states in terms of the configurations as proposed for ^{106}Cd by Samuelson et al. [15] who used the shell-model parentage of the largest components in their wave functions.

4.2 Electric quadrupole transition probabilities

Kern et al. [5] have interpreted the 10^+ level at 3611 keV (cf. Fig. 2) as a two-quasineutron configuration the $\nu(h_{11/2})^2$ being the head of a rotational band built on top of it. As can be seen from Table 1, there is a considerable difference between the absolute probabilities for the E2 transitions linking this state with the three lower-lying 8^+ levels. The largest one, B(E2, $10^+ \Rightarrow 8_3^+$) = 33.5 W.u. reveals a collective character of this transition and confirms the $\nu(h_{11/2})^2$ intrinsic structure of the 8_3^+ state. The other value, B(E2, $10^+ \Rightarrow 8_2^+$) = 7.7 W.u. indicates small but appreciable $\nu(h_{11/2})^2$ admixtures in the 8_2^+ level belonging to the ground state band (gsb). The very low transition strength B(E2, $10^+ \Rightarrow 8_1^+$) = 0.054 W.u. points at a fully different structure of the states involved. This is in accordance with our findings concerning the yrast 8^+ states in $^{104-108}$Cd [10] characterized as $\pi(g_{9/2})^2$ configurations.

Fractions of the collective bands associated with the $\nu(h_{11/2}d_{5/2})$ configuration (8_1^- -10_1^- -12-1 etc.) and the $\nu(h_{11/2}g_{7/2})$ one (7_1^-–9_1^-–11_1^- etc.) are shown in Fig. 2. We observe strong E2 transition from the 8_1^- level with B(E2, $8_1^- \Rightarrow 6_1^-$) = 20 W.u. This is evidence that the 6_1^- level is a member of the same $\nu(h_{11/2}d_{5/2})$ band. In this way, the irregular level spacing at the bottom of the band typical for the semi-aligned bands in ^{106,108}Cd is established in ^{110}Cd, too. Using the E2/M1 mixing ratio of the 177.6 keV transition from [5] we derived B(E2, $8_1^- \Rightarrow 7_1^-$) = 14 W.u. which indicates that at lower spins appreciable mixing occurs between the above mentioned collective bands.

The low transition rates determined for the 219 and 339 keV E2 transitions (cf. Fig. 2 and Table 1) lead to the conclusion that the 7_1^- state is the lowest member of

Table 1. Electromagnetic transition probabilities in ^{110}Cd. Data were taken from [1, 5] and the present work

E^a_{lev} (keV)	$T^b_{1/2}$ (ns)	$J_i^{\pi c}$	$J_f^{\pi d}$	E^e_γ (keV)	I^f_γ	σL^g	α^h_{tot}	$B(\sigma L)^i$ (W.u.)
3611	0.45(10)	10^+	8_3^+	171.3	14.2	E2	0.22	33.5(8.5)
			9_1^-	265.2	4.3	E1	0.011	$1.3(3)\times10^{-6}$
			8_2^+	335.6	93.9	E2	0.023	7.7(1.8)
			8_1^+	423.5	2.1	E2	0.011	$5.4(1.8)\times10^{-2}$
3056	2.25(10)	8_1^-	6_1^-	159.7	23.9	E2	0.28	20(1)
			7_1^-	176.5^j	56.6	M1	0.098	$5.1(2.6)\times10^{-4}$
						E2	0.2	14(7)
3029	0.30(10)	7_2^-	7_1^-	149.9	4.8	M1	0.15	$1.6(7)\times10^{-3}$
			5_2^-	369.2	4.4	E2	0.017	0.6(3)
			5_1^-	489.4	22.9	E2	0.007	0.8(3)
			6_1^+	549.1	30.5	E1	0.002	$2.9(1.0)\times10^{-6}$
2879	0.60(10)	7_1^-	5_2^-	219.3	3.5	E2	0.094	0.9(2)
			5_1^-	339.5	57.9	E2	0.022	1.6(3)
			6_1^+	399.2	180	E1	0.004	$5.8(1.0)\times10^{-6}$

[a] Level energy in keV
[b] Half-life of the level in ns
[c] Spin and parity of the initial (i) state
[d] Spin and parity of the final (f) state
[e] Transition energy in keV
[f] Relative γ-ray intensity
[g] Transition multipolarity
[h] Theoretical internal conversion coefficient [14]
[i] Absolute transition rate in W.u.
[j] Mixing ratio $\delta = -1.03(54)$ [5]

the $\nu(h_{11/2}g_{7/2})$ band and support the two-quasiproton character of the 5_1^- and 5_2^- states as discussed in [1].

The 3^-–5_1^-–7_2^-–9_2^-–11_2^- etc. sequence (see Fig. 2) has been considered by Kern et al. [5] as an octupole band. In [1], it has been proposed that at higher spins the structure of this octupole band changes to a more pure $\nu(h_{11/2}d_{5/2})$ quasiparticle configuration. As follows from our measurements (s. Table 1), the probabilities for the E2 transitions depopulating the 7_2^- state are of single-particle character (0.9 and 1.6 W.u., respectively) and exclude a collective nature of the 7_2^- to 5_1^- or 7_2^- to 5_2^- transition. Having in mind the two-quasiproton character of both 5^- states [1] to which the 7_2^- level decays, it can be suggested that the 7_2^-–9_2^-–11_2^- sequence represents indeed the odd-spin members of the $\nu(h_{11/2}d_{5/2})$ structure starting at spin 7.

In general, the negative-parity states are expected to be mixed by the rotation. Nevertheless, the $\nu(h_{11/2}d_{5/2})$ and $\nu(h_{11/2}g_{7/2})$ labels can be used for a qualitative classification of the corresponding bands.

4.3 Electric dipole transition probabilities

All the E1 transition probabilities measured in this work (Table 1) are about two order of magnitude lower than the value of 1.4×10^{-4} W.u. assumed in subs. 4.1. as a measure for the E1 octupole strength. This means that these E1 transitions proceed without appreciable octupole admixtures. This statement holds also for the 549 keV transition linking the 7_2^- level at 3029 keV with the gsb and thus excludes an octupole origin of the 7_2^- state. In this way, the above conclusion drawn from the E2 strengths for the two-quasiparticle nature of this level is further supported.

5 Concluding remarks

Applying the generalized-centroid shift method the half-lives of four excited states in ^{110}Cd were determined and the corresponding transition probabilities have been derived. In this way, we extend the systematics of the $\nu(h_{11/2}d_{5/2})$ semi-aligned bands to ^{110}Cd, confirm the $\nu(h_{11/2})^2$ structure of the 10^+ state at 3611 keV and localized a new two-quasiparticle state at 3029 keV.

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