Some aspects of the ^{111}Cd level scheme

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The level scheme of ^{111}Cd has been studied by measuring singles and coincident γ-ray spectra following neutron capture by ^{110}Cd. Despite good experimental conditions, only six γ rays were observed. The intensity balances at the 396-, 342-, and 245-keV levels are discussed. The results support the assumption that the 284-keV γ ray, emitted from the 680-keV state, is the dominant population mode of the 49-min isomer at 396 keV.

The level scheme of ^{111}Cd has been studied from β decay,[1] Coulomb excitation,[2-4] (d,p), (d,t),[5] $(\alpha,3n\gamma)$,[6] (d,d'),[7] (p,p),[8] (n_{res},γ),[9] and $(n,n'\gamma)$[10] reactions, and photoexcitation.[11-15] Over 20 excited states below 1332 keV have been established, but their disintegration modes remain partly obscure. The excitation of the isomeric state at 396 keV has been observed during photoactivation of ^{111}Cd with ^{60}Co γ rays. It was assumed that the resonantly activated states are the 1330- and/or 1190-keV states[11-15] but the intermediate levels through which the photoactivation takes place have not been determined with certainty.[13] It is this point which we wish to investigate by neutron capture in ^{110}Cd. The resonantly excited state in the (γ,γ') reaction must have a low spin since the ground state has $I^{\pi}=\frac{1}{2}^{+}$. The s-wave neutron-capture state must be $\frac{1}{2}^{+}$, since the target has $I^{\pi}=0^{+}$, and the low-lying levels populated by primary γ rays will then have spins of $\frac{1}{2}$ or $\frac{3}{2}$ and either parity. Therefore, the neutron-capture reaction may populate the same levels as the (γ,γ') reaction and thereby provide some information as to the feeding of the 396-keV isomer.

The experiment was carried out at the high flux reactor at the Institute Laue-Langevin, Grenoble. The cadmium target and detectors were located 120 m from the reactor core at the end of a neutron guide. This allows the experiment to be made in a low background region.

The neutron flux at the target position was 7.8×10^{8} cm^{-2}s^{-1}. Capture γ rays were detected with two coaxial Ge(Li) detectors of 20% efficiency and resolutions of 2.1 keV at 1.33 MeV. The data were collected for 3.1 days in the event-by-event mode and from these the coincidence matrix was constructed. Two different targets were used: one of natural Cd containing 12.5% of ^{110}Cd, and the second with ^{110}Cd enriched to 95.6%. In both cases the dominant process was the production of ^{114}Cd nuclei irrespective of the small ^{113}Cd content in the second target (the abundance was 0.5%). This was due to the large neutron capture cross section of ^{113}Cd $[\sigma(n,\gamma)=1.98\times10^{4}$ b] and the comparatively small capture cross section for ^{110}Cd $[\sigma(n,\gamma)=11$ b (Ref. 16)].

The most intense lines in the γ-ray spectra were those from ^{114}Cd. The energy calibration, the energy dependence of the line-shape parameters, and the detector efficiency curve were all based on the known lines of ^{114}Cd.[17] The lines assigned to ^{111}Cd were determined by comparing the spectra from the enriched and natural Cd targets.

In the direct and coincidence spectra only six lines could be ascribed to ^{111}Cd. Their relative intensities are presented in Table I, column 6. In the same table E_i, J_i and E_f, J_f denote the energy, spin of the initial and final states of the associated transition. The intensity of the 151-keV γ ray is corrected for the contribution of a similar energy γ ray in ^{114}Cd. The long measurement time al-

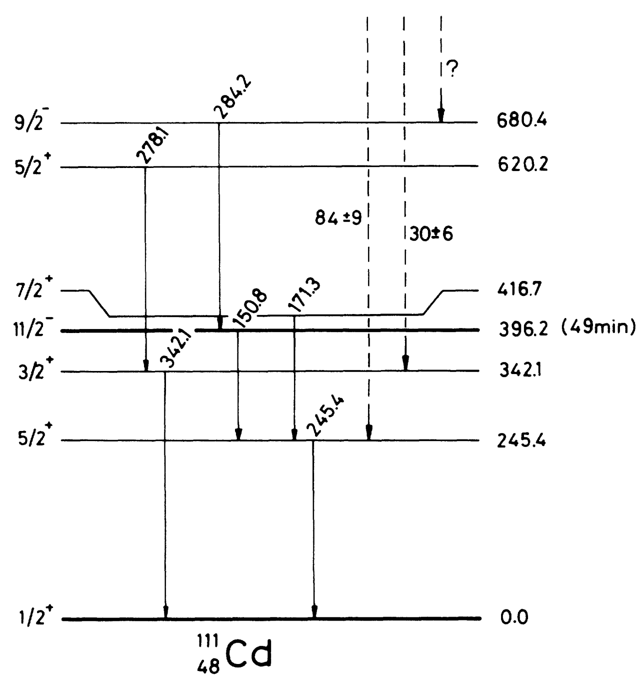

FIG. 1. The lower part of the level scheme of ^{111}Cd. The dashed line and the numbers beside them show the unobserved feeding of the levels.

TABLE I. Energies and relative intensities of γ lines obtained from direct and coincidence spectra of ^{111}Cd and the assigned transitions.

E (keV)	E_i (keV)	J_i	E_f (keV)	J_f	I_γ	I
150.8	396.2	$\frac{11}{2}^-$	245.4	$\frac{5}{2}^+$	4(3)	12(9)
171.3	416.7	$\frac{7}{2}^+$	245.4	$\frac{5}{2}^+$	8(3)	9(3)
245.4	245.4	$\frac{5}{2}^+$	0	$\frac{1}{2}^+$	100	107
278.1	620.2	$\frac{5}{2}^+$	342.1	$\frac{3}{2}^+$	25(3)	26(3)
284.2	680.4	$\frac{9}{2}^-$	396.2	$\frac{11}{2}^-$	15(2)	16(2)
342.1	342.1	$\frac{3}{2}^+$	0	$\frac{1}{2}^+$	53(5)	54(5)

lowed the intensities of the γ rays depopulating the 49-min isomer to reach equilibrium.

Baskova *et al.*[9,10] were the first to establish [during the study of ^{111}Cd through $^{110}\text{Cd}(n_{\text{res}},\gamma)^{111}\text{Cd}$ and $^{111}\text{Cd}(n,n'\gamma)^{111}\text{Cd}$ reactions] the 680-keV $\frac{9}{2}$ level which feeds the isomeric level by a strong 284-keV transition. Németh *et al.*[13] assumed that this 396-keV $\frac{11}{2}$ isomeric level was populated dominantly by this transition, and also that the 680-keV level deexcited only to the isomeric level.

This assumption and some other details of the ^{111}Cd level scheme can be tested by checking the intensity balance at the 396-, 342-, and 245-keV levels (see Fig. 1). The total transition intensities $I=I_\gamma(1+\alpha_T)$ needed for such calculations are presented in the last column of Table I. The conversion coefficients[18] α_T of all the observed transitions, except the 151-keV, are small and thus the data[13,16] on the transition multipolarities do not affect significantly the derived I values. The conversion coefficient of the strongly converted 151-keV $E3$ transition is accurately measured.[19]

It is established that the 342-keV level decays by 342 keV and 97 keV γ rays with branchings of 96% and 4%, respectively. Thus the intensity balance at this level is

$$I(278)+I_U(\underline{342})=\frac{1}{0.96}I(342)\ , \tag{1}$$

where $I_U(\underline{342})$ is the sum of unobserved transition intensities feeding the 342-keV level. From the measured values, Table I, we derive $I_U(\underline{342})=30\pm6$. This means that our measured intensity for the 278-keV γ-ray accounts only for about the half of the intensity feeding the 342-keV level, while the other half should be attributed to several low intensity or highly converted transitions.

The only depopulation of the 396-keV isomeric state is by the 151-keV transition. Thus the intensity balance of this isomer is

$$I_U(\underline{396})+I(284)=I(151)\ , \tag{2}$$

where again $I_U(\underline{396})$ is the sum of the unobserved transition intensities feeding the isomer and the 284-keV transition. From our data it follows the $I_U(\underline{396})<5$. This result supports the assumption of Németh and Veres[13] about feeding the 49-min isomer.

The intensity balance at the 245-keV level is

$$I_U(\underline{245})+I(171)+I(151)+0.04[I(278)+I_U(\underline{342})]=I(245)\ , \tag{3}$$

which gives for the sum of unobserved transitions feeding the 245-keV level $I_U(\underline{245})=84\pm9$. The observed intensities are far from satisfying the intensity balance at the 245-keV level. Only about 20% of the intensity feeding this level is seen in our experiment.

The serious lack of intensity balances at two low-lying levels shows that the level scheme of ^{111}Cd is far from complete. Bearing in mind all these problems it seems necessary to prepare a pure ^{110}Cd target by burning out the ^{113}Cd content in a high flux reactor or carrying out a second isotope separation and using it to study in much more detail the levels of ^{111}Cd populated by neutron capture.

It does appear that the dominant feeding mode of the 49-min isomer by neutron capture and photoexcitation is established.

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