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LIFETIMES OF THE LOW-LYING $\frac{7}{2}^-$ STATES IN ^{113,115}Cd

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Abstract: The half-lives of the $\frac{7}{2}^-$ states at 522.6 and 393.9 keV in ^{113}Cd and ^{115}Cd have been determined to be 0.322 ± 0.012 and 0.75 ± 0.03 ns, respectively. Values of the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ and the energy difference $E_{7/2^-} - E_{11/2^-}$ in odd Cd (A = 113–119) are compared with those in neighbouring even Cd. The level properties are interpreted in the framework of the triaxial rotor model.

E | RADIOACTIVITY ^{113,115}Ag [from ^{114,116}Cd(γ, p)]; measured $\beta\gamma$, $\gamma\gamma(t)$. ^{113,115}Cd levels deduced $T_{1/2}$, B(M1), B(E2). Enriched targets, NaI(Tl) plastic scintillation detectors.

1. Introduction

Recently, the band structures in odd-A nuclei near the spherical region ($Z \approx 50$) have been studied by in-beam spectroscopy [1,2]. The band structures for such nuclei have been interpreted by the core-particle coupling concept. Several models have been proposed for the core, i.e. the vibrational model [3,4]) or the rotor model [5–7]). For a test of the various models, both the decoupled band built on the $h_{\frac{11}{2}}$ unique parity orbital and the unfavoured states give important information, especially about deformation parameters and the position of the Fermi level. The study of the lower-spin unfavoured states is, however, greatly hampered by the weak population in in-beam spectroscopy.

Recent studies of the β^--decay of odd Ag isotopes have revealed the existence of low-lying $\frac{7}{2}^-$ and $\frac{9}{2}^-$ states in ^{113}Cd [ref. [8])], ^{115}Cd [ref. [9])], ^{117}Cd [ref. [10])] and ^{119}Cd [ref. [11])]. The lowest $\frac{7}{2}^-$ state may be considered as resulting from antiparallel coupling of the particle spin $j = \frac{11}{2}$ and the core spin $R = 2$. The $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2})$ was also obtained in ^{117,119}Cd [refs. [10,11])]. It is noteworthy that the value in ^{119}Cd is significantly smaller than that in ^{117}Cd, although the transition energy in ^{119}Cd is lower than that in ^{117}Cd. The present experiment was undertaken to determine the lifetimes for the $\frac{7}{2}^-$ levels in ^{113,115}Cd and to compare them with the prediction of the current theoretical model [5]).

2. Experimental procedure and results

The ^{113}Ag ($T_{\frac{1}{2}}$ = 5.3 h) and ^{115}Ag ($T_{\frac{1}{2}}$ = 20 min) sources were produced *via* the (γ, p) reaction on a metallic foil of ^{114}Cd (enriched to 99 %) and the oxide powder of ^{116}Cd (enriched to 97 %). The targets were irradiated by bremsstrahlung converted from a 50 MeV electron beam of the electron linear accelerator at the Japan Atomic Energy Research Institute. The partial decay schemes of ^{113,115}Cd are shown in figs. 1a and 1b where only those levels and transitions pertinent to the present measurements are shown. The $\frac{3}{2}^-$ states at 1194.6 and 1092.1 keV in ^{113}Cd and ^{115}Cd are strongly populated by the β^--decay of the parent ($\frac{1}{2}^-$) states of ^{113,115}Ag with $\log ft$ = 7.1 and 7.0, respectively.

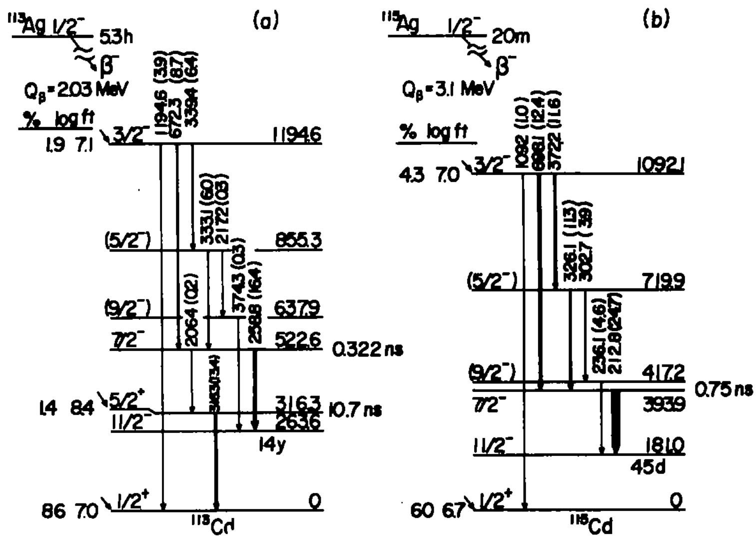

Fig. 1. (a) Partial decay scheme of ^{113}Ag. (b) Partial decay scheme of ^{115}Ag. Relative intensities of the γ-rays are given in parentheses.

The half-lives of the excited states in ^{113,115}Cd were studied by β-γ and γ-γ delayed coincidence technique. In the β-γ coincidence measurements, we used a 5.1 cm × 5.1 cm diam. plastic scintillator for detection of β-rays and a 5.1 cm × 5.1 cm diam. NaI(Tl) detector for γ-rays, both of which were coupled to RCA 8575 photomultiplier tubes. The γ-γ coincidence measurements were performed with two plastic scintillators of identical dimension, 5.1 cm × 5.1 cm diam. The coincidence events were recorded on magnetic tape in the three-parameter mode; the data were analysed off line. Prompt coincidence curves were obtained using a ^{60}Co source.

The half-lives in ^{113}Cd. For the gate setting at E_β = 320–800 keV and E_γ = 259, 333+359, 672 keV photo-peaks, which are related to the negative parity levels, the half-life of the 522.6 keV level was found to be shorter than 0.35 ns, almost the limit of the present NaI(Tl) plastic coincidence arrangement. In order to determine the half-life of this state accurately the γ-γ coincidence were performed. Strong coincidence relationships were already known between the $\frac{9}{2}^- \rightarrow \frac{7}{2}^-$ (672.3 keV) and $\frac{7}{2}^- \rightarrow \frac{11}{2}^-$ (258.8 keV) transitions in ^{113}Cd [ref. [8])]. Therefore, the parts of the Compton spectra due to the 258.8 and 672.3 keV γ-rays were selected in the counters as the start and stop signals, respectively. A typical time spectrum is shown in fig. 2a. Additional analyses of the time spectra with various start-stop signal gates

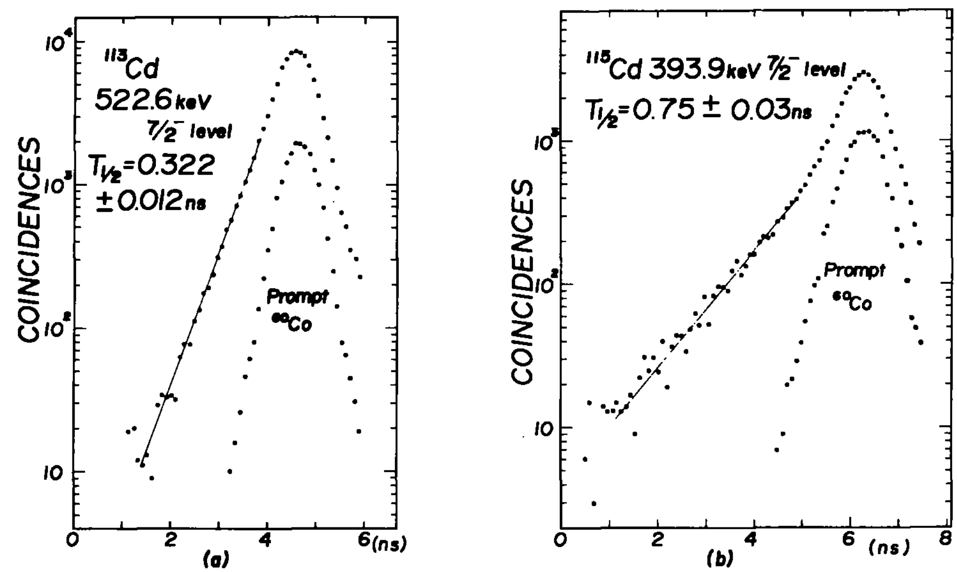

Fig. 2. (a) Half-life measurement of the 522.6 keV level in ^{113}Cd from the γ-γ coincidence. (b) Half-life measurement of the 393.9 keV level in ^{115}Cd from the γ-γ coincidence.

confirmed that the measured half-life was due to the 522.6 keV level. From a least-squares fit to the logarithmic slope, we obtained

$$T_{\frac{1}{2}}\ (522.6\ \text{keV}) = 0.322 \pm 0.012\ \text{ns}.$$

The half-life of the 316.3 keV $\frac{3}{2}^+$ state was obtained from the β-γ coincidence

$$T_{\frac{1}{2}}\ (316.3\ \text{keV}) = 10.7 \pm 0.4\ \text{ns}.$$

This value coincides with 11.6 ± 0.8 ns as reported by Raman *et al.* [12]), but differs from the value of 6.7 ± 0.8 ns by Andreev *et al.* [13]).

The half-life in ^{115}*Cd.* The half-life for the $\frac{7}{2}^-$ level at 393.9 keV in ^{115}Cd was studied as for ^{113}Cd. From the β-γ coincidence between the β-ray (260–1500 keV) and the 213 keV γ-ray, a half-life of 0.79 ± 0.09 ns was found. Also, from the γ-γ coincidence between the part of Compton spectra due to the 212.8 and 698.1 keV

γ-rays, the half-life of the $\frac{7}{2}^-$ level was determined

$$T_{\frac{1}{2}}\,(393.9\text{ keV}) = 0.75 \pm 0.03\text{ ns}.$$

The time spectrum is shown in fig. 2b.

3. Discussion

The experimental results are summarized in table 1 together with the predictions of the weak coupling model and the triaxial model [5]). The data of ^{117}Cd and ^{119}Cd are taken from ref. [10]) and ref. [11]), respectively. The B(E2) values are plotted in

TABLE 1

Summary of the lifetime measurement of the $\frac{7}{2}^-$ state

Nucleus	$T_{1/2}$(ns) exp	Transition E_γ (keV) $\frac{7}{2}^- \to (I_f)$	Partial γ half-life (ns)	B(E2) ($e^2\cdot$b^2) B(M1) (μ_N^2) B(E1) ($e^2\cdot$b)	1/HF [a])	Theory B(E2) ($e^2\cdot$b^2) weak coupling	Theory B(E2) ($e^2\cdot$b^2) rotation aligned [b]) (triaxial core)
^{113}Cd	0.322(12)	258.8($\frac{11}{2}^-$) (E2)	0.343	0.142(6)	44	0.101	0.127 (γ = 23°)
		206.4 ($\frac{5}{2}^+$) (E1)	28	$1.8(2)\times10^{-8}$	1.2×10^{-6}		
^{115}Cd	0.75 (3)	212.8($\frac{11}{2}^-$) (E2)	0.75	0.157(7)	47	0.106	0.134 (γ = 23°)
^{117}Cd [c])	3.6 (2)	157.1($\frac{11}{2}^-$) (E2)	4.7	0.13(1)	37	0.106	0.147 (γ = 21°)
		15.0 ($\frac{9}{2}^-$) (M1)	> 643	$< 1.8\times10^{-2}$	< 0.01		
^{119}Cd [d])	43 (3)	81.7($\frac{11}{2}^-$) (E2)	217	0.072(6)	21		
		14.3 ($\frac{9}{2}^-$) (M1)	$\geq 5.1\times10^3$	$\leq 2.6\times10^{-3}$	$\leq 1.6\times10^{-3}$		

a) HF denotes the retardation factor relative the Weisskopf single particle unit.
b) Model parameters $\beta A^{2/3} = 5$, $\lambda_F = \varepsilon_1$ from ref. [5]). γ-parameter was estimated for $E_{4_1^+}/E_{2_2^+}$.
c) From ref. [10]).
d) From ref. [11]).

fig. 3 with those in neighbouring even Cd nuclei [14]). In fig. 4 the energy systematics of negative parity states is also shown and compared with the 2^+ states of even Cd. The $B(\text{E2}, \frac{7}{2}^- \to \frac{11}{2}^-)$ values in ^{113,115}Cd are considerably larger than the average values in even Cd nuclei. The lack of experimental data on the $2^+ \to 0^+$ transitions in ^{118,120}Cd makes further quantitative comparison with the weak-coupling model difficult in ^{117,119}Cd. However, one would expect no large variation of the $B(\text{E2}, 2^+ \to 0^+)$ values in even Cd (A = 112–122) from the small variation of the $2^+ \to 0^+$ energies in these nuclei [15]). On the contrary, the $B(\text{E2}, \frac{7}{2}^- \to \frac{11}{2}^-)$ values decrease rapidly with the mass number from A = 115 to A = 119. These aspects indicate that the states cannot be explained using the weak-coupling mechanism.

A simple and intuitive explanation for the antiparallel alignment of the spins j (particle) and R (rotor) is given by Meyer-ter-Vehn using the triaxial-rotor-plus-

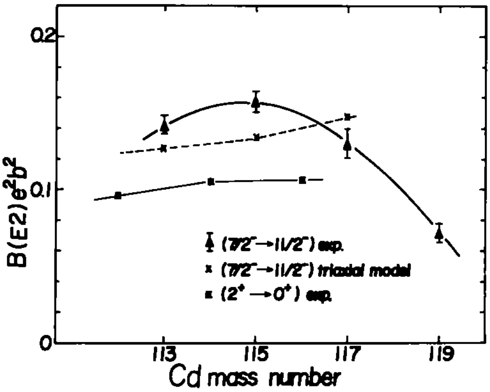

Fig. 3. Comparison of the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ values in odd Cd with the $B(\mathrm{E2}, 2^+ \rightarrow 0^+)$ values of the neighbouring even Cd and the triaxial model calculations [5]).

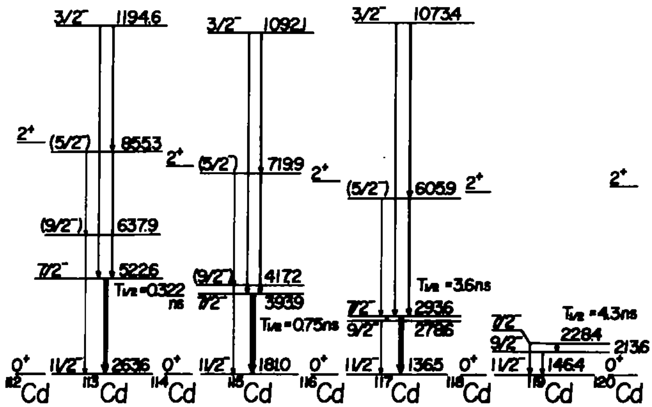

Fig. 4. Comparison of the negative parity states in odd Cd with the 2^+ states of the neighbouring even Cd.

particle model [5]). According to this model, the rotation-aligned vector system gradually localizes about the $\hat{2}$ axis as γ changes from 0° toward 60°. Then, the B(E2) value is approximately given by

$$B(\mathrm{E2}, (j-2) \rightarrow j) \approx \frac{5}{16\pi} \left| q_{22}^{(2)} \right|^2 = \frac{5}{16\pi} Q_0^2 \, \tfrac{1}{2} \sin^2(\gamma - 60°),$$

where $q_{22}^{(2)}$ is the intrinsic quadrupole tensor for the $\hat{2}$ axis and Q_0 is the intrinsic quadrupole moment. This indicates that the B(E2) value decreases rather sharply with γ because the nuclear shape becomes symmetric about the $\hat{2}$ axis which results in $q_{22}^{(2)} \rightarrow 0$.

The experimental results of the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ values in ^{113,115,117}Cd are seen to follow closely the predictions of the triaxial model [5]) shown in fig. 3. The values of γ were obtained from $E_{4^+}/E_{2'^+}$ ratios in even Cd. In ^{116,118}Cd the γ-values

($\gamma = 21°$) are smaller than those ($\gamma = 23°$) in ^{112,114}Cd. In the triaxial model, the smaller value of γ give the larger $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)/(5Q_0^2/16\pi)$, while the experimental result indicates an oppositie tendency. To explain the decrease of the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ values in ^{117,119}Cd, other effects must be included. One possible effect may be due to mixing of the $f_{\frac{7}{2}}$ orbit, which belong to the next upper major shell. However, no such mixing has been observed in the ^{116}Cd(d, p) reactions [16,17]. Other effects may be due to the variation of the Fermi level λ_F. With increasing neutron number, λ_F would penetrate the $h_{\frac{11}{2}}$ shell. This affects strongly the energy of the lower spin state in the triaxial model [5]. The fact that the energies of the negative parity low-spin states except for the $\frac{3}{2}^-$ state shown in fig. 4 decrease with increasing neutron number agrees with the theoretical model prediction [5]. In that case where the j-shell is approximately half filled, three-quasi-particle correlations may be included, especially for the $\frac{9}{2}^-$ state [18,19]. On the other hand, the $B(\mathrm{E2})/(5Q_0^2/16\pi)$ values between high-spin decoupled states are known to be rather independent of the parameters $\beta A^{\frac{4}{3}}$ and the Fermi level λ_F in the triaxial model [20].

We found that the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ values in ^{113,115,117}Cd were reasonably interpreted in the framework of the triaxial model. However, the tendency for the $B(\mathrm{E2}, \frac{7}{2}^- \rightarrow \frac{11}{2}^-)$ values to decrease across the odd Cd isotopes ($A = 115$–119) has not been explained so far by this model. Also, more experimental results, especially for high-spin states are necessary to test the validity of various models.

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