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Lifetime measurement of excited states in ^{109}Cd

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The levels up to 1135 keV in ^{109}Cd were excited via ^{109}Ag$(p,n\gamma)$ reaction. For the first time, the lifetimes of energy levels at 673, 721, 821, 891, 997, 1106, and 1135 keV have been measured using Doppler shift attenuation technique.

[NUCLEAR REACTION ^{109}Ag$(p,n\gamma)$, $E_p=3.4$ and 3.9 MeV; measured lifetime; DSA technique.]

The excited states of ^{109}Cd have been studied earlier by several workers[1–7] through different reactions and β^+ decay of ^{109}In. The experimental information up to 1978 has been summarized by Bertrand.[8] A survey of available literature reveals that the lifetimes of the levels beyond 462 keV have not been reported so far. The present work was, therefore, undertaken to measure the lifetimes of higher excited states. Since the electromagnetic matrix elements are the most sensitive tools to test the theoretical calculations, the present experimental results would, therefore, be very useful in revealing the nuclear structure of ^{109}Cd.

The excited states of ^{109}Cd were observed following the reaction ^{109}Ag$(p,n\gamma)^{109}$Cd using 3.4- and 3.9-MeV proton beams from the Chandigarh cyclotron. The target employed was a self-supporting foil of spectroscopically pure natural Ag, which was thick

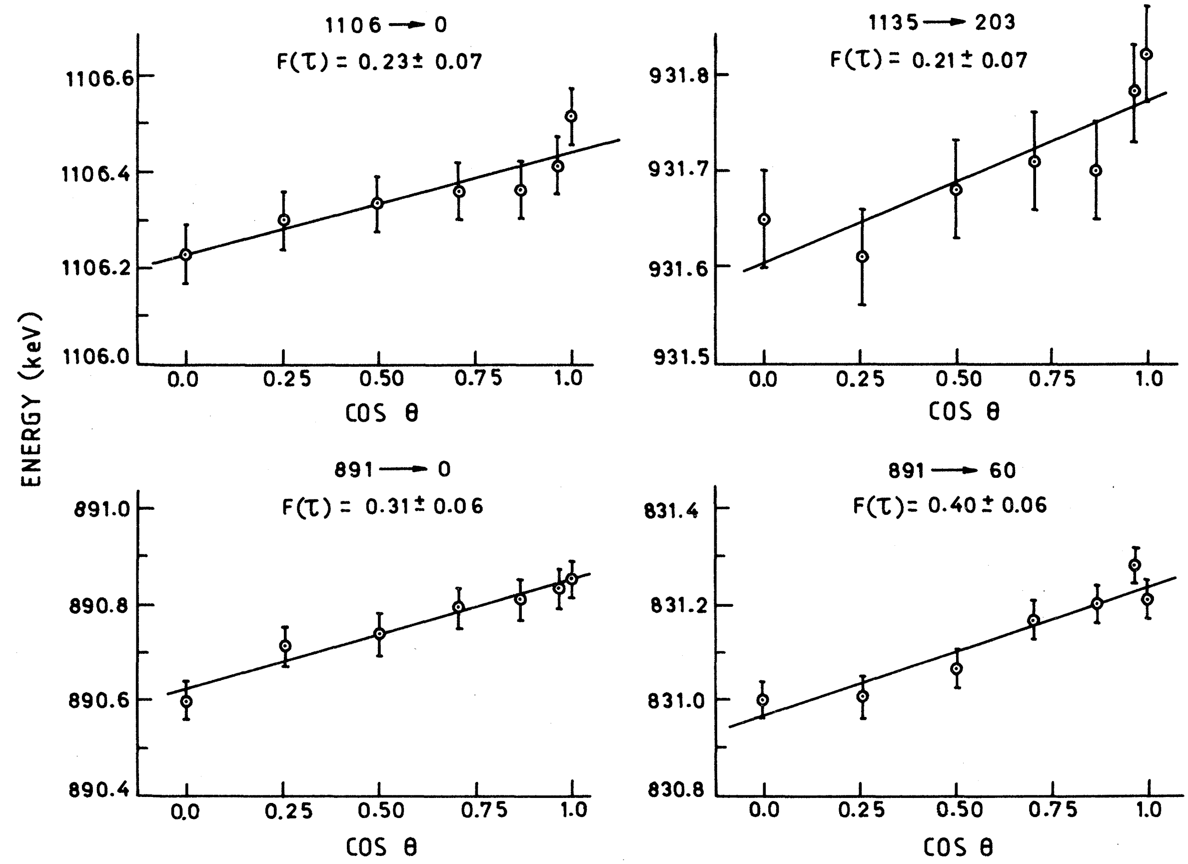

FIG. 1. Plots of E_θ vs $\cos\theta$ for several γ transitions in ^{109}Cd. The straight lines represent the least-squares fits to the experimental data.

enough to absorb incident protons. The γ rays were detected in a 50-cm^3 Ge(Li) detector having 2.0-keV resolution at 1.3 MeV. Singles γ-ray spectra were recorded at 90°, 75°, 60°, 45°, 30°, 15°, and 0° with respect to the beam direction. The shift in gain was monitored by observing the γ rays from ^{137}Cs and ^{60}Co radioactive sources before and after recording the spectrum at each angle. At each angle, a number of spectra (four or five) were recorded in order to ensure the reliability of the measurements and the sets of experiments with gain drift greater than 0.05 keV were rejected. A further check on the shift of gain was made by observing the γ rays which were known to have no Doppler shift because their lifetimes were greater than 10^{-12} sec. The energy and efficiency calibration was performed using ^{60}Co, ^{137}Cs, and ^{152}Eu radioactive sources. The γ-ray spectra were analyzed using the computer code SAMPO.[9,10] The accuracy of γ-ray energies is not better than 0.2 keV, which includes the error due to uncertainty in photopeak location and the error in energy calibration. However, the accuracy of the Doppler shift is considerably higher since it includes the error in photopeak location only, which in our case is about 0.05 keV. The experimental values of the attenuation factor $F(\tau)$ for different γ rays were calculated from the slopes of straight lines which were least-squares fits to the experimental data, using the relation

$$E_\theta = E_{90}[1+\beta(0)F(\tau)\cos\theta] ,$$

where E_θ is the energy of the γ ray at an angle θ from the beam direction and $\beta(0)$ is the velocity of recoiling nuclei in forward direction (along the beam axis). The plots of E_θ vs $\cos\theta$ and their best fits for some of the γ rays are shown in Fig. 1. Since the bombarding energy of protons is near the threshold of the levels studied, it is therefore safe to assume that the recoiling nuclei of ^{109}Cd make a narrow forward cone. The initial recoil velocity of ^{109}Cd was calculated from kinematics. Since the nuclear levels were populated via compound nucleus formation, the angular distribution of outgoing neutrons was assumed to be symmetric about 90° in the center-of-mass system.

Theoretical $F(\tau)$ vs τ were calculated in the framework of the Lindhard-Scharff-Schiøtt (LSS)[11] theory taking into account the Blaugrund[12] approximation for nuclear scattering. The values of $f_e = f_n = 1$ were taken in the stopping power formula

$$\left(\frac{dE}{dx}\right)_{\text{tot}} = f_e\left(\frac{dE}{dx}\right)_{\text{electronic}} + f_n\left(\frac{dE}{dx}\right)_{\text{nuclear}}$$

so as to reproduce the earlier reported[8] lifetime of the 702-keV state in ^{109}Ag populated via ^{109}Ag$(p,p'\gamma)$ reaction.

TABLE I. Excitation energy of the levels, attenuation factors, and lifetimes for γ transitions deexciting the levels of ^{109}Cd. The lifetimes of the levels beyond 891 keV have been measured using 3.9-MeV protons while the lifetimes of levels up to 891 keV have been measured using 3.4-MeV protons. The error in experimental $F(\tau)$ is due to the uncertainty in the location of the peak.

E_{level} (keV)	E_γ (keV)	Experimental $F(\tau)$	Lifetime (τ) (fs)
673.2(4)	613.6(2)	0.28(5)	80^{+22}_{-18}
721.2(2)	721.2(2)	0.17(5)	150^{+70}_{-40}
	518.0(2)	0.24(5)	100^{+30}_{-25}
821.0(3)	821.0(3)	0.19(6)	130^{+70}_{-40}
890.6(3)	890.6(3)	0.31(6)	68^{+22}_{-16}
	831.0(3)	0.40(6)	45^{+15}_{-10}
997.4(4)	794.2(2)	0.22(6)	110^{+50}_{-30}
	571.4(2)	0.26(6)	85^{+35}_{-20}
1106.2(3)	1106.2(3)	0.23(7)	105^{+55}_{-35}
1134.9(5)	931.7(3)	0.21(7)	120^{+80}_{-40}

The excitation energy and lifetime of the levels are summarized in Table I. The errors in lifetimes are corresponding to the errors in experimental values of $F(\tau)$. However, an additional error up to 20% may be attributed to the results due to the uncertainty in nuclear stopping power, which predominates at the recoil velocity ($\beta = 0.08\%$) of ^{109}Cd nuclei for incident protons of 3.9 MeV.

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