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Identification and decay of ^{124}Ag

John C. Hill and F. K. Wohn
Ames Laboratory, Iowa State University, Ames, Iowa 50011

Z. Berant
Ames Laboratory, Iowa State University, Ames, Iowa 50011
and Brookhaven National Laboratory, Upton, New York 11973

R. L. Gill and R. E. Chrien
Brookhaven National Laboratory, Upton, New York 11973

C. Chung
University of Maryland, College Park, Maryland 20742

A. Aprahamian
Clark University, Worcester, Massachusetts 01610
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The decay of mass-separated ^{124}Ag to ^{124}Cd was studied by γ singles and $\gamma\gamma$ coincidence measurements. A half-life for ^{124}Ag of 0.17 ± 0.03 s was measured. The one γ ray from ^{124}Ag decay observed at 613 keV is postulated to depopulate the 2_1^+ state in ^{124}Cd. The resulting extension of the systematics of even-even Cd isotopes is discussed.

[RADIOACTIVITY ^{124}Ag, ^{124}Cd [from ^{235}U(n,f)]; measured $T_{1/2}$, E_γ, I_γ, $\gamma\gamma$ coin for ^{124}Ag, ^{124}Cd measured $T_{1/2}$; Ge(Li) detectors; ^{124}Cd deduced levels J, π. Mass-separated ^{124}Ag and ^{124}Cd activity.]

Recently Reeder, Warner, and Gill[1] reported the observation of the new isotope ^{124}Ag on the basis of the measurement of its delayed neutron emission. A ^{124}Ag half-life of 0.54 ± 0.08 s was reported and the neutron emission probability was found to be $> 0.1\%$. No studies of γ transitions following the decay of ^{124}Ag have been reported, and there is no prior information on excited states in ^{124}Cd.

The structure of the even-even Cd nuclei ^{112}Cd and ^{114}Cd has been of recent interest due to the observation of a quintuplet of states where the normal two-photon triplet of the spherical vibrational model is expected to occur. For ^{118}Cd and higher masses this quintuplet structure seems to have disappeared and the more normal triplet structure reemerges.

The quintuplet structure in ^{112}Cd and ^{114}Cd has been successfully explained by Heyde *et al.*[2] in terms of the interaction of 2p-2h proton excitations with quadrupole vibrational excitations of the Cd core. The unusual electromagnetic decay pattern of the 0_3^+ member of the quintuplet was reproduced by constructive interference between strong $E2$ vibrational and quasirotational decay amplitudes. The decay properties and energies of the 2_1^+, 4_1^+, 0_2^+, and 2_2^+ states agree qualitatively[2] with that of the spherical vibrational model.

The energies for the 2_1^+ and 4_1^+ states in even-even Cd nuclei are minimal at $A = 118$ and increase symmetrically as neutron pairs are added or removed. This trend is clear for $A = 114$ to 122. If one assumes that these states are primarily vibrational in character, the minimum at $A = 118$ may be related to the midpoint of some appropriate neutron subshell. We thus undertook this study of the decay of ^{124}Ag to levels in ^{124}Cd in order to extend the systematics of even-even Cd nuclei to higher mass numbers.

Sources of mass-separated ^{124}Ag and ^{124}Cd were produced by the TRISTAN mass separator factility on-line to the High Flux Beam Reactor at Brookhaven National Laboratory. TRISTAN has been described in detail elsewhere.[3,4] Beams of $A = 124$ ions were obtained from a FEBIAD (forced electron bombardment induced arc discharge) target ion-source system containing ~ 2 g of ^{235}U loaded on a hollow graphite cylindrical anode and operated at a temperature of $\sim 1700\,^\circ$C. The ion source was placed in an external neutron beam with a flux of $\sim 2 \times 10^{10}$ n/cm^{2}s.

The γ singles, γ multispectrum scaling (GMS), and $\gamma\gamma$ coincidence measurements were carried out simultaneously using two HpGe detectors each located about 1.5 cm from the beam collection spot in a 180° geometry. The outputs of both detectors were gated with pulses from a β scintillation detector in order to reduce background. During the beam collection and data accumulation cycle the ion beam was collected on the tape of a moving tape collection system for 0.5 s followed by a 1.5-s counting period during which the $A = 124$ beam was deflected. The total running time for the main run was 154 h.

The GMS counting period of 2 s was divided into 16 time bins of 0.125 s length. Comparison of various GMS spectra revealed only one γ ray that could be assigned to ^{124}Ag decay. Its energy was determined to be 613.2 ± 0.2 keV using a ^{152}Eu energy standard. A spectrum resulting from summing of GMS time bins 1 through 6 and covering the energy range from 500 to 1100 keV is shown in Fig. 1(a). The peak at 614 keV consists of a doublet with components at 613 keV from ^{124}Ag and 615 keV from ^{124}In decay. The spectrum in Fig. 1(b) obtained by summing GMS time bins

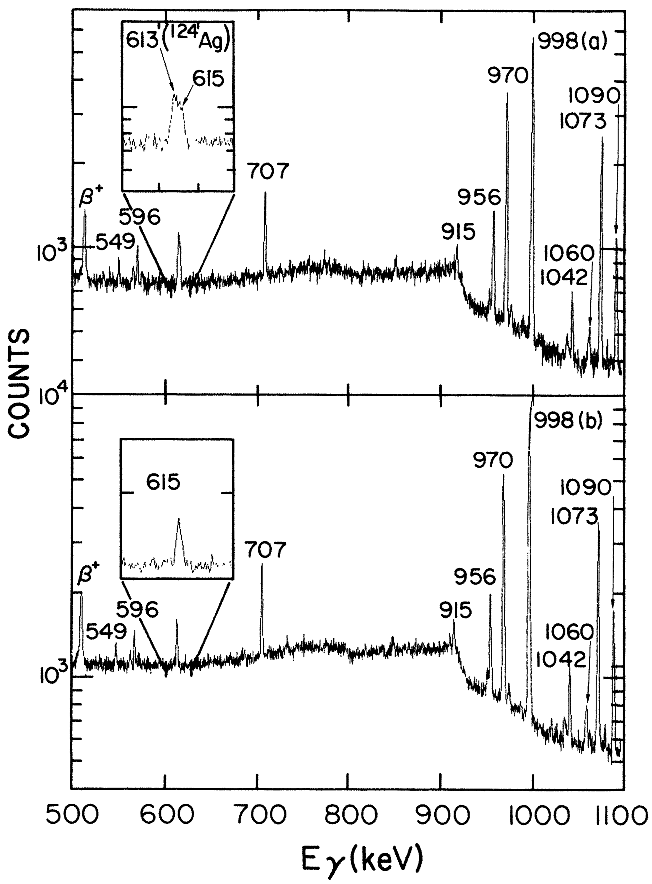

FIG. 1. GMS γ spectra for the decay of ^{124}Ag and other members of the $A=124$ chain. (a) Sum of time bins 1 through 6. (b) Sum of time bins 11 through 16.

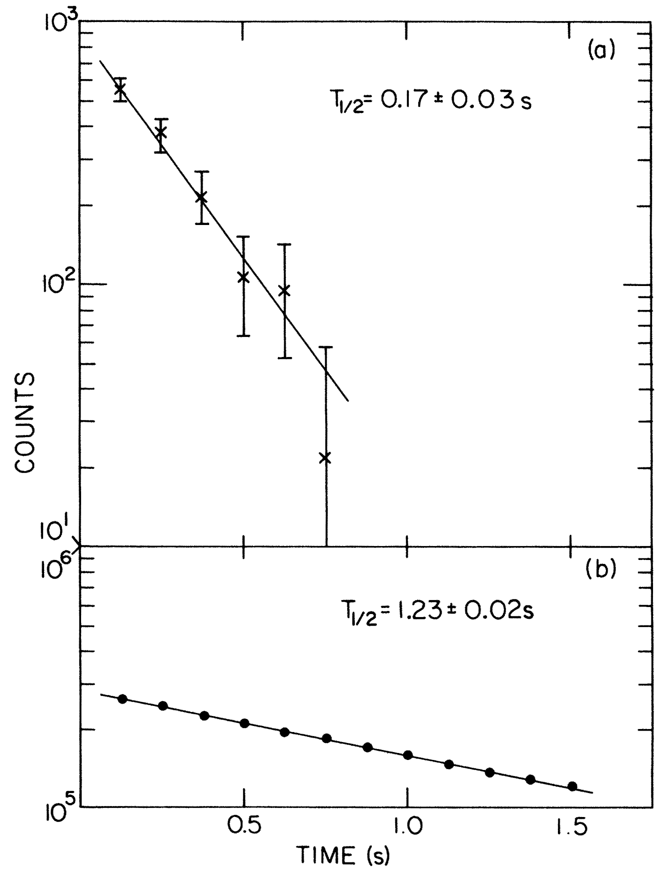

FIG. 2. Decay curve for (a) the 613-keV γ ray from ^{124}Ag decay and (b) the 180-keV γ ray from ^{124}Cd decay.

11 through 16 shows only the single γ ray at 615 keV. All other labeled γ rays are from decays of $^{124}In^{g}$ and $^{124}In^{m}$ except the 596-keV peak from neutron capture in the Ge detectors and annihilation radiation.

The GMS data for the 613-keV γ ray was used to determine the half-life of ^{124}Ag. The resulting decay curve is shown in Fig. 2(a). Due to low counting rates dead-time corrections were negligible. A curve for the 180-keV γ ray from ^{124}Cd decay is shown in Fig. 2(b) for comparison. The measured ^{124}Cd half-life was 1.23 ± 0.02 s, in excellent agreement with a recent measurement of 1.2 ± 0.1 s by Reeder *et al.*[1] using the technique of β multiscaling. We measured the ^{124}Ag half-life to be 0.17 ± 0.03 s in disagreement with the value of 0.54 ± 0.08 s measured[1] by neutron multiscaling.

The coincidence data were collected event by event on disk and dumped to magnetic tape. A total of 4.3×10^{6} events were recorded but most were from ^{124}Cd and ^{124}In decays. A spectrum in coincidence with the doublet at 614 keV showed only two peaks at 1090 and 1132 keV which are in cascade[5] with the 615-keV transition from the decay of 3.2 s $^{124}In^{g}$. The 613-keV γ ray from ^{124}Ag decay was not seen in the spectrum in coincidence with the 1132-keV γ ray.

We attribute the single γ ray at 613.2 keV with a half-life of 0.17 s to come from the decay of ^{124}Ag. The mass assignment is based on $A=124$ mass separation and observation of other peaks in the γ spectrum only from the decays of ^{124}In, ^{124}Cd, or background. It is unlikely that the 613-keV γ ray results from the decay of an unknown isomer of ^{124}Cd or ^{124}In. Isomerism is not known in other even-even Cd isotopes and from structural considerations is not to be expected. Isomerism is well established[5] in the odd-odd isotopes. Fogelberg and Carle[5] have postulated the two isomers of ^{124}In to have J^{π} values of 3^{+} and $(8)^{-}$, respectively. Thus any additional β decaying isomer of ^{124}In would be expected to have a higher spin and deexcite by β decay followed by a γ cascade through the 2_1^{+} level in ^{124}Sn at 1132 keV, but a coincidence between the 1132-keV γ ray and the 613-keV transition was not seen. If the 613-keV transition was from an isomeric γ transition in ^{124}In, coincidence with the 1132-keV transition would not be seen but a short-lived component would be observed in the decay curves of prominent γ rays from ^{124}In decay. Neither of the above effects were seen. Finally, the transition energy of 613 keV is consistent with the systematics for 2_1^{+} levels in even-even Cd nuclei as discussed below. Although the above does not absolutely exclude the placement of the 613-keV γ ray as coming from an isomer of ^{124}In, we believe that the postulate that is proceeds from the β decay of ^{124}Ag is far more reasonable.

Our half-life for ^{124}Ag of 0.17 ± 0.03 s is not in agreement with the 0.54 ± 0.08-s result determined at TRISTAN by

Reeder *et al.*[1] by delayed neutron counting. The reason for this discrepancy is not obvious but the possibility exists that delayed neutron emission results from the β decay of a different isomer of ^{124}Ag than that seen in this work. The gross theory of β decay[6] predicts the half-life of ^{124}Ag to be roughly half that of ^{122}Ag ($T_{1/2}=0.48\pm0.08$, 0.57 ± 0.03),[1,7] which is consistent with our result. In absolute value the prediction[6] is too high by about a factor of 10 in each case.

We postulate the 613-keV γ ray observed from ^{124}Ag decay to depopulate the 2_1^+ level in ^{124}Cd. No other information is available on excited states in ^{124}Cd. A careful search was made in sums of various GMS spectra and in the coincidence spectrum obtained by gating on the 613-keV transition for γ rays that would depopulate 0_2^+, 2_2^+, and 4_1^+ levels in ^{124}Cd but none were found. We also calculated the log*ft* for the β transition to the 2_1^+ level in ^{124}Cd using $Q_\beta=10.78$ MeV from the tables of Möller and Nix[8] and assuming a range from 20 to 100% β feeding to the level. The corresponding log*ft*'s range from 5.6 to 4.9, indicating the J^π for the ^{124}Ag ground state to be probably 1^+, 2^+, or 3^+. 3^+ seems less likely since no population of the 4_1^+ state in ^{124}Cd was observed.

The systematics for 2_1^+, 4_1^+, and 2_2^+ states in even-even Cd nuclei with $A=112$ through 124 are shown in Fig. 3. Particularly striking are the minima in energies of the 2_1^+ and 4_1^+ states at $A=118$ ($N=70$) and their symmetric rise in energy as neutron pairs are either added or removed. The behavior of the 2_2^+ level is somewhat different and reaches an energy minimum at $A=114$ rather than 118. The 613-keV energy for the 2_1^+ level in ^{124}Cd (^{118}Cd+6 neutrons) is almost identical to the 617-keV 2_1^+ level in ^{112}Cd (^{118}Cd−6 neutrons).

The energy minimum at $A=118$ is suggestive of the existence of a subshell whose midpoint is at $N=70$. The ordering of neutron quasiparticle energies in odd-A Zr isotopes is $2d_{5/2}$, $3s_{1/2}$, $1g_{7/2}$, $2d_{3/2}$, and $1h_{11/2}$ as obtained from the weighted average of energy centroids in (d,p) reactions.[9,10] ^{89}Sr gives similar orderings.[11] For these Sr and Zr nuclei, the $3s_{1/2}$ state is ~1 MeV above the $2d_{5/2}$ and also ~1 MeV below the $1g_{7/2}$, $2d_{3/2}$, and $1h_{11/2}$ states. Thus neutron subshell gaps are expected at $N=56$ and $N=58$. The influence of these subshells on the structure of nuclei with $Z\sim40$ and $N\sim56$ is discussed by Sistemich *et al.*[12] The minima at $N=70$ observed in the even-A Cd isotopes may be interpreted as evidence that there is also no significant neutron subshell closure between $N=58$ and $N=82$, hence a minimum in the 2_1^+ energy occurs at the midpoint of a nearly degenerate ($1g_{7/2}$, $2d_{3/2}$, $1h_{11/2}$) subshell, i.e., at $N=70$.

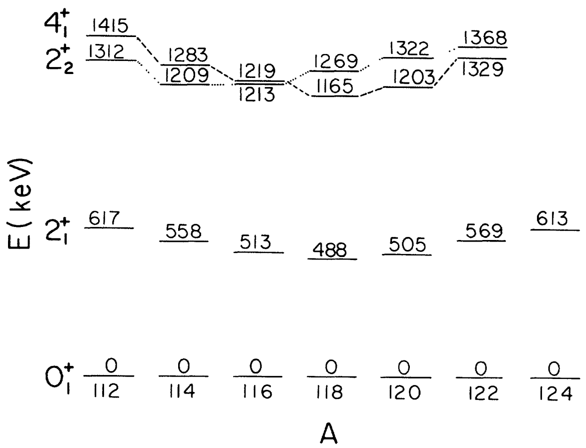

FIG. 3. Systematics for 2_1^+, 4_1^+, and 2_2^+ states in even-even Cd isotopes with $A=112$–124.

In this paper we have presented the first information on levels in ^{124}Cd. We would also like to obtain a more detailed level scheme for ^{124}Cd in order to define the vibrational triplet and determine the trend in energy of the 4_1^+ state, but more intense neutron fluxes and or more efficient ion sources than those presently available at TRISTAN would be needed.

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