Decay of Pd^{111} and Pd^{111m}

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(Received 18 December 1964; revised manuscript received 8 April 1965)

The decay of 22-min Pd^{111} and 5.5-h Pd^{111m} was studied using scintillation-spectrometer and coincidence techniques. The 22-min activity was studied in equilibrium with Pd^{111m} and also independently, and it was observed to emit gamma rays of energies 70, 160, 280, 385, 400, 500, 560, 630, 750, 830, 960, 1130, 1380, and 1440 keV. Gamma rays of energies 1080, 1250, 1640, 1690, and 1900 keV were observed only in the decay of 5.5-h activity. The beta spectrum of both the activities extends up to 2110 keV. From the beta-gamma and gamma-gamma cascade relationships, a decay scheme with levels in Ag^{111} at 70, 120, 280, 385, 470, 560, 1015, 1220, 1515, 1640, 1760, 1810, 1850, and 1970 keV has been proposed. Possible spins and parities for these levels are discussed.

I. INTRODUCTION

THE decay of 22-min Pd^{111} and 5.5-h Pd^{111m} has been studied earlier by McGinnis,[1] Pratt *et al.*,[2] and Eccles.[3] The studies by McGinnis indicated that the 5.5-h isomer, Pd^{111m}, is characterized by a 2150-keV beta group and a 170-keV isomeric transition, while a beta group ($E_{max}\sim$2100 keV) followed by 60-keV conversion electrons is associated with the 22-min decay of the ground state of Pd^{111}. Pratt *et al.* obtained the source by neutron irradiation of 91.4% enriched Pd^{110} and studied the decay by means of a plastic phosphor and NaI(Tl) scintillation spectrometer. According to them the 22-min activity decayed mostly by 2180±100-keV beta transition to 70-keV isomeric state of Ag^{111}, while a weak beta transition of 2020±100-keV could be associated with the decay of 5.5-h Pd^{111m}. These authors also attributed gamma rays of energy 377, 580, 620, 810, 1380, and 1450 keV to the decay of 22-min activity, and those of 170 and 1690 keV to the decay of the 5.5-h isomer, respectively. Eccles has suggested a scheme of energy levels of Ag^{107}, Ag^{109}, and Ag^{111} on the basis of measurement of singles gamma spectra and by comparing the systematics of the low-lying levels of the odd proton isotopes in this mass region. So far, no detailed coincidence work has been carried out on the decay of Pd^{111} and Pd^{111m}.

The excited states of Ag^{107} and Ag^{109} have also been investigated[4] by the inelastic scattering of protons and deuterons. The investigations have pointed out energy levels at 328, 425, 784, and 948 keV in Ag^{107} and at 313, 416, 701, and 861 keV in Ag^{109}, thus indicating a marked similarity in the low-lying energy levels of these silver isotopes. Cohen *et al.*[5] have pointed out that the levels that are excited strongly in Coulomb excitation are also strongly excited in inelastic proton scattering, and vice versa. Thus the low-lying energy levels of odd-mass Ag isotopes may have collective nature, and may arise because of the coupling of the quadrupole vibrations of the even-even core with the particle motion. In fact the levels at 318 and 413 keV in Ag^{107} and 305 and 400 keV in Ag^{109} have been discussed by de-Shalit[6] as the levels due to the coupling of the first phonon with $\frac{1}{2}^-$ ground state. The main evidence is the reduced $E2$ matrix elements, for the transitions from these levels to the ground state, which are of the order of the $E2$ matrix elements for the $2^+\rightarrow 0^+$ transitions in the neighboring even-even nuclei.

The present study was initiated to establish the energy levels of Ag^{111} from the decay of Pd^{111} and Pd^{111m} and then to compare them with the neighboring isotopes. This work has been carried out by utilizing gamma-gamma and beta-gamma coincidence techniques with scintillation phosphors. The levels in Ag^{105}, Ag^{107}, Ag^{109}, and Ag^{111} are represented in Fig. 1.

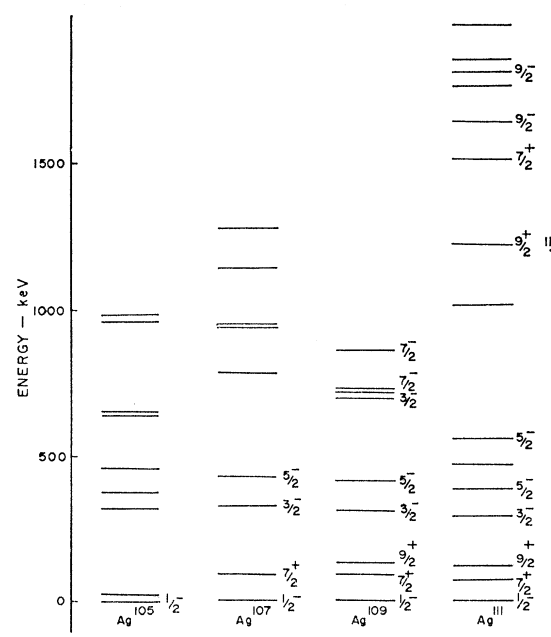

FIG. 1. Systematics of energy levels in odd-A silver isotopes.

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The data for Ag^{105}, Ag^{107}, and Ag^{109} have been taken from Nuclear Data Sheets[7] and those for Ag^{111} have been collected from the present work. The marked similarity in the low-lying levels is very evident.

II. MEASUREMENTS AND RESULTS

A. Source Preparation

An enriched sample of Pd^{110} (91.4%) was obtained from Oak Ridge National Laboratory. The samples were irradiated in Apsara Reactor at Trombay with a flux of 30×10^{11} neutrons/cm²-sec. For the study of the decay of the 22-min ground state of Pd^{111} the sample was irradiated for 20 min and then chemically purified from any contamination of Ag^{110} and Na^{24}. In a similar way the 5.5-h isomer of Pd^{111} was studied by irradiating the samples for 10 h and then chemically purifying them.

B. The Gamma-Ray Spectrum

The gamma-ray spectra of 22-min Pd^{111} and 5.5-h Pd^{111m} as obtained with a 3-in.-diam×3-in.-thick NaI(Tl) crystal and a 512-channel analyzer are given in Figs. 2(a) and 2(b), respectively. In these measurements the source was kept at a distance of 10 cm from the crystal and a $\frac{1}{2}$-in.-thick Perspex absorber was used for absorbing the beta particles.

The spectrum in Fig. 2(a) was recorded 20 min after the irradiation and the decay of each gamma ray was followed for four half-lives. This spectrum extends only up to 1400 keV and all the gamma rays decay with a half-life of 22 min, except the 160-keV peak which decays faster because of the partial contribution of the 188-keV transition in 4.7-min Pd^{109m}. The spectrum in Fig. 2(b) belonging to 5.5-h Pd^{111m} extends up to 1900 keV. From the comparison of the above two spectra it is inferred that the 1900-, 1690-, 1640-, 1250-, and 1080-keV gamma rays are present only in the decay of 5.5-h activity. It is also seen from Fig. 2(b) that the intensities of the 160-, 290-, 400-, 500-, and 750-keV gamma rays are considerably enhanced indicating that these gamma rays are present in both the activities.

The singles gamma spectrum in Fig. 2(b) was analyzed in the usual way by using standard line shapes and the intensities of various gamma rays as normalized to a value of 100 for the intensity of the 630-keV gamma ray are given in Table I. The intensity of the 70-keV gamma ray is not included in this table as this is very much enhanced due to the 88-keV isomeric transition in Pd^{109}.

TABLE I. The intensities of various gamma transitions as obtained from the analysis of singles gamma spectrum.

E (keV)	Intensity	E (keV)	Intensity
160±5	620	830±10	10.3
280±10	71.1	900±20	8.9
295±10		960±20	11.5
385±10	177.3	1080±15	18.1
400±10		1130±15	17.2
450±15	36.4	1250±15	15.9
500±10	32.2	1380±15	8.8
560±10	67.6	1440±15	5.0
630±10	100	1640±20	22.6
750±15	39	1690±20	11.1
		1900±20	8.6

C. Gamma-Gamma Coincidences

The gamma-gamma coincidence measurements were carried out with two scintillation spectrometers consisting of 3-in.×3-in. NaI(Tl) crystals mounted on Dumont 6363 photomultiplier tubes. The coincidence arrangement was the usual fast-slow type with a resolving time $2\tau=0.12\ \mu$sec, without any loss in the coincidence efficiency above 50 keV. Proper source strengths have been used so that the true/chance ratio has always been above 10. The coincidence efficiency was confirmed to be 100% above 50 keV, using the annihilation radiation from a Na^{22} source. The two detectors were placed at 180° with a suitably graded anti-Compton shield in between them in order to prevent spurious coincidences. All the coincidence spectra were recorded on a 512-channel analyzer. The measurements were carried out on the chemically purified, 5.5-h Pd^{111m} activity which was in equilibrium with the 22-min Pd^{111} ground state. Separate measurements were also made on the decay of 22-min Pd^{111} alone. This shorter lived activity was obtained by irradiating samples of enriched Pd^{110} for 20 min and studying it immediately without carrying out any chemical purification. The conclusions from the gamma-gamma coincidence measurements are thus primarily based on the data from the 5.5-h Pd^{111m} in equilibrium with the 22-min ground state while the data obtained from the decay of 22-min activity alone have been used for comparing and checking these conclusions.

The study of the gamma-gamma coincidences was begun from the high-energy end of the gamma spectrum and the gate was shifted successively towards the lower end of the spectrum in steps of ~100 keV. In order to distinguish the genuine coincidences we compared the coincidence spectrum having the gate at the photopeak of a particular gamma ray with the coincidence spectrum having the gate at the energy which was higher than this photopeak. Such comparison helped in estimating the coincidences due to the Compton contribution of the high-energy gamma rays.

No conclusive evidence was obtained for any gamma ray that was in coincidence with the photopeak of the 1900-keV gamma ray. The gamma spectrum in coincidence with the 1630-keV gamma ray showed a single photopeak at 50 keV. No appreciable coincidences were

[7] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Science–National Research Council, Washington, D. C.), NRC 60-5-135 and NRC 60-2-47.

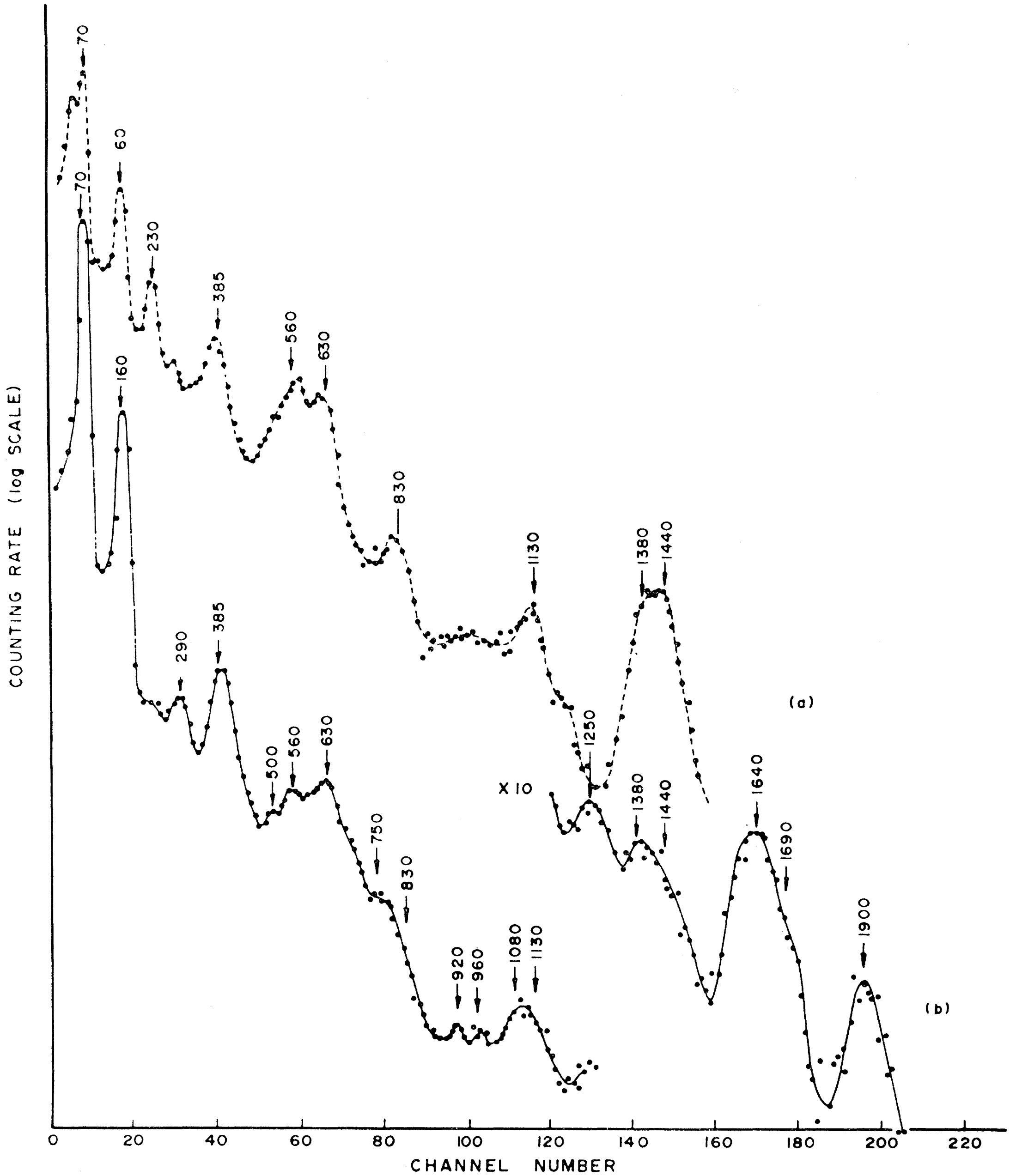

FIG. 2. (a) Pd^{111} gamma-ray spectrum (22-min activity). (b) The gamma-ray spectrum of 5.5-h Pd^{111m}. This spectrum was taken with a source in equilibrium with 22-min activity.

observed after lowering the gate up to 1450 keV. A photopeak at 400 keV was observed in the coincidence spectrum [Fig. 3(a)] when the gate was in the region of 1380 keV. The coincidence spectra with the gate at the 1300- and 1250-keV energy regions are shown in Fig. 3(b) and Fig. 3(c), respectively. It may be mentioned here that the gate at 1300 keV partially includes the photopeaks of the 1250- and 1380-keV gamma rays. It is concluded that the larger intensity of the photopeaks at 160, 280, 385, and 560 keV, as the gate is shifted from 1300 to 1250 keV, is caused by this former group of gamma rays' being in coincidence with the 1250-keV gamma ray. The intensity of the 385-keV photopeak is relatively greater than the intensity of the 160-keV photopeak as seen from the coincidence spectrum of Fig. 3(c), though we have postulated a 1250–160–385-keV cascade in the decay scheme. This difference might be due to the fact that the gate at 1250 keV partially accepts the photopeak of the 1130-keV gamma ray and the Compton background of the 1380-keV

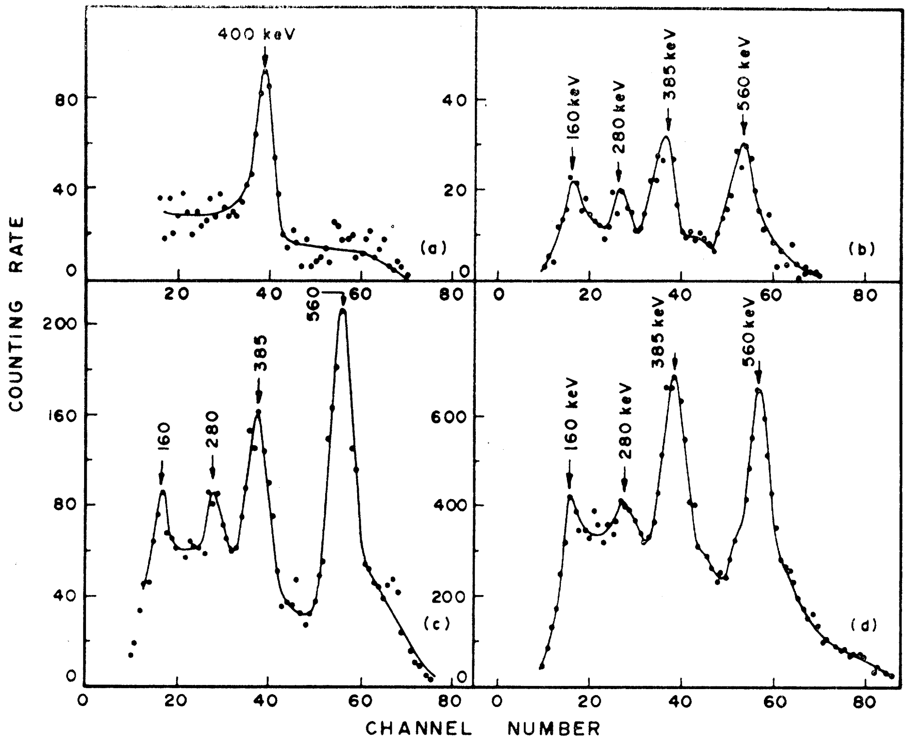

FIG. 3. The gamma ray spectra in coincidence with (a)–1380-keV photopeak; (b)–1300-keV region; (c)–1250-keV photopeak; (d)–1100-keV region, in the gate.

gamma ray. After lowering the gate into the energy region 1080–1130 keV, photopeaks are observed [Fig. 3(d)] at 160, 280, 385, and 560 keV, thus indicating a coincidence between these gamma rays and either 1080- or 1130-keV gamma ray. It is further observed from Fig. 3(d) that the intensity of the 560-keV photopeak is reduced as compared to the intensity of the 385, 280, and 160-keV photopeaks. This could be explained by the possibility that the 1130-keV gamma ray alone might be in coincidence with the 290- and 385-keV gamma rays. This is supported by the fact that the 1130-keV gamma ray has been observed in the 22-min activity and its coincidence with the 290- and 385-keV gamma rays has also been observed in the

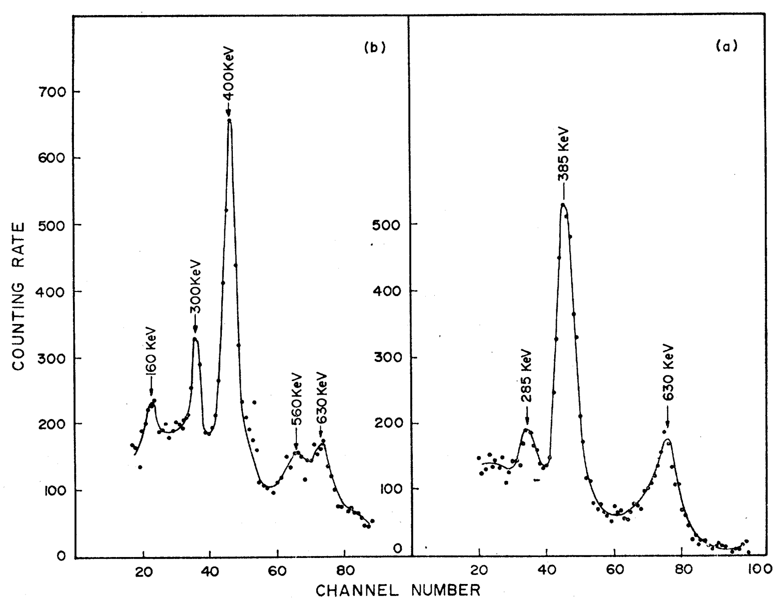

FIG. 4. The gamma-ray spectra in coincidence with (a)–750-keV photopeak region; (b)–830-keV photopeak in the gate.

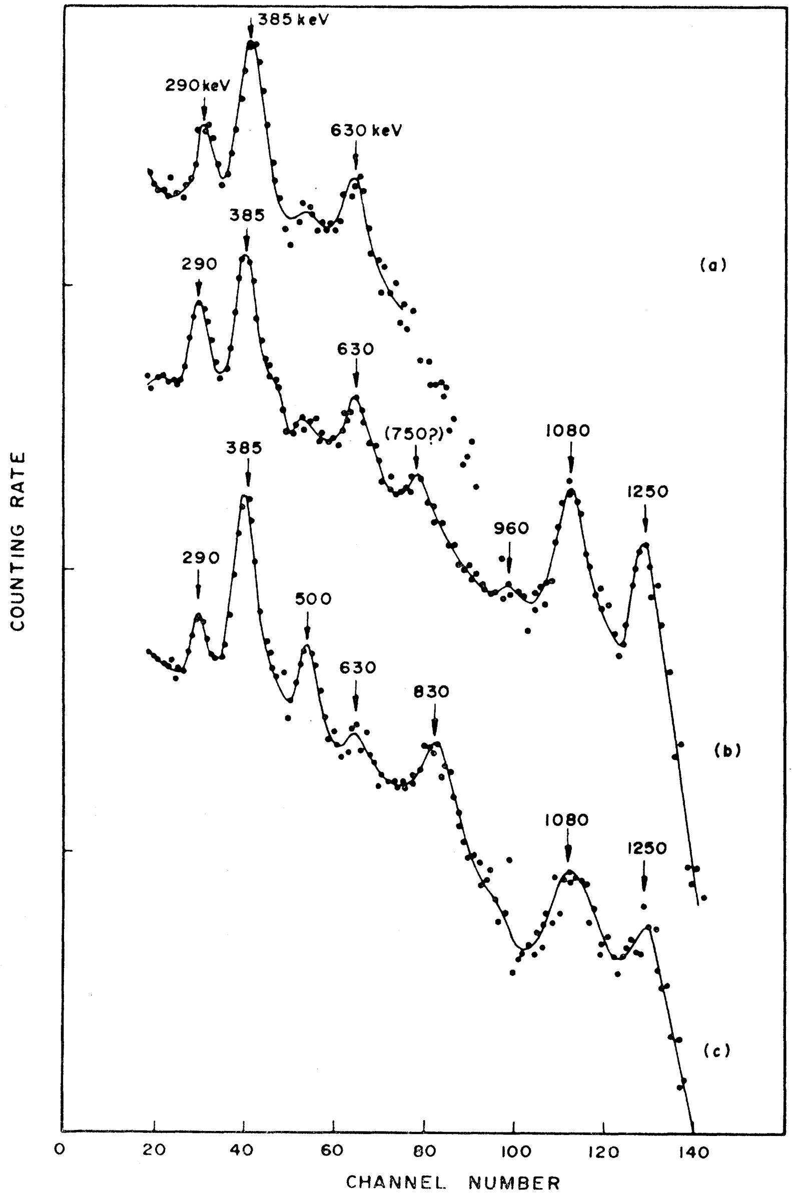

FIG. 5. The gamma-ray spectra in coincidence with (a)–500-keV photopeak region; (b)–560-keV photopeak region; and (c)–630-keV photopeak region in the gate.

22-min activity. Again the gamma spectrum in coincidence with the 560-keV gamma ray [Fig. 5(b)] has indicated photopeaks at 1080 and 1250 keV.

The gamma spectrum in coincidence with the 830-keV gamma ray has been studied from the decay of the 22-min activity of Pd^{111} and is shown in Fig. 4(a). The 830-keV gamma ray is observed very clearly in the 22-min activity and as seen from Fig. 4(a) it is in coincidence with the 630- and 385-keV gamma rays. The weak peak at 285 keV and the larger intensity of the 385-keV peak is probably due to the partial acceptance of the 750-keV gamma ray in gate. The gamma spectrum in coincidence with the 750-keV gamma ray is shown in Fig. 4(b). In this case the source was prepared from the 5.5-h activity in equilibrium with the 22-min activity of Pd^{111}. The photopeaks at 160, 560, and 630 keV in the coincidence spectrum [Fig. 4(b)] could probably be due to the partial acceptance of the 830-keV photopeak and the Compton contribution of the high-energy gamma rays in the gate, while those at 300 and 400 keV are due to the genuine coincidences of the 750-keV gamma ray.

The gamma spectra in coincidence with the 500-, 560-, and 630-keV photopeak regions in the gate are shown in Figs. 5(a), 5(b), and 5(c), respectively. In these spectra it is evident that the peaks at 960, 1080, and 1250 keV appear to be strongest [Fig. 5(b)] when the 560-keV region is in the gate, thus indicating that the three gamma rays at 960, 1080, and 1250 keV are in coincidence with the 560-keV gamma ray. As described

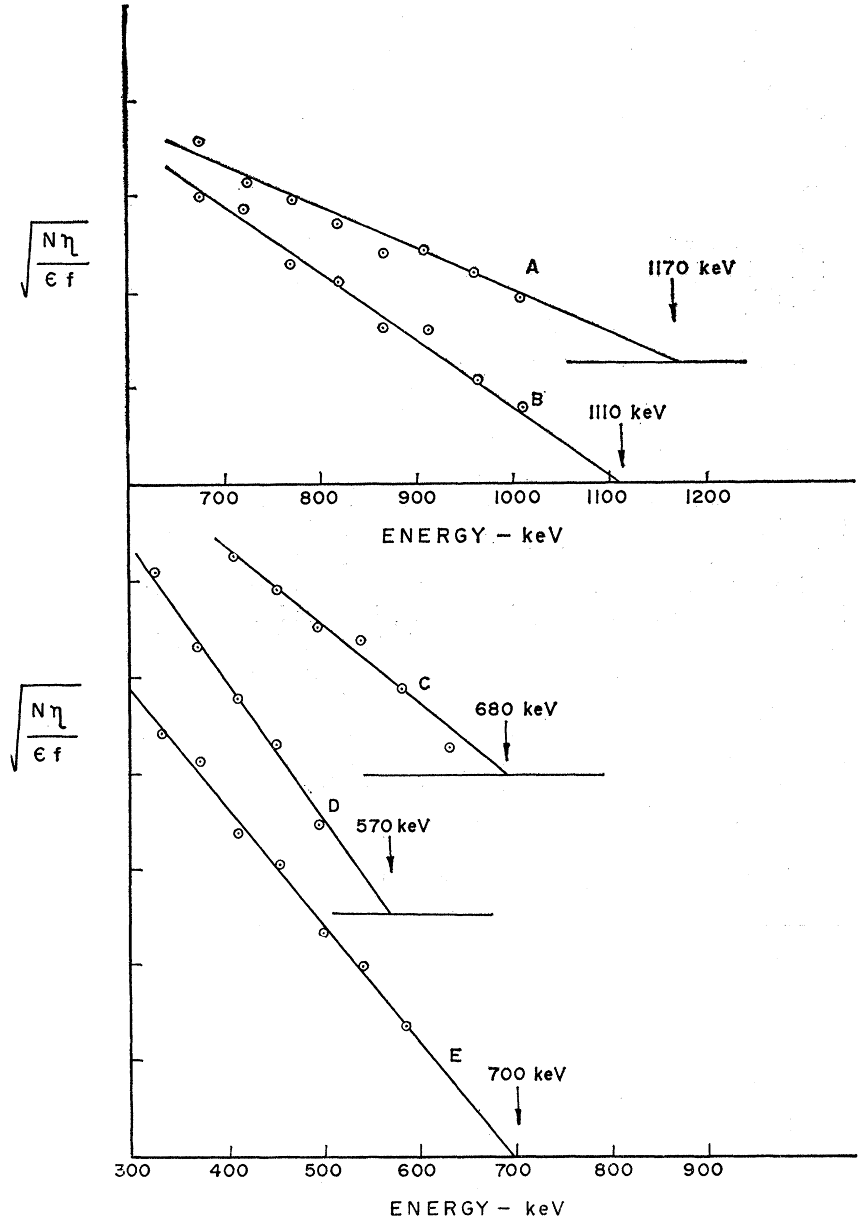

FIG. 6. Fermi plot of the beta spectra in coincidence with (A)–630-keV gamma ray; (B)–750-keV gamma ray; (C)–1440-keV gamma ray; (D)–1640-keV gamma ray; (E)–1080-keV gamma ray.

above, a peak at 560 keV has already been observed in the coincidence spectra with the 1080- and 1250-keV photopeaks in the gate. In Fig. 5(c) the peaks at 820 and 500 keV appear to be relatively stronger, indicating that these gamma rays are in coincidence with the 630-keV gamma ray. Similarly a coincidence between 630- and 500-keV gamma rays is suggested by the strong peaks at 500 and 630 keV in Figs. 5(c) and 5(a), respectively. A photopeak at 385 keV appears in all the coincidence spectra Figs. 5(a), 5(b), and 5(c). However, when the 385-keV gamma ray was taken in the gate, photopeaks at 500 and 630 keV were observed in the coincidence spectrum. On this basis it appears that the 385-keV gamma ray is in coincidence with the 500- and 630-keV gamma rays and that the peak in coincidence spectrum [Fig. 5(b)] is perhaps due to the partial acceptance of the 500- and 630-keV gamma rays when the gate was fixed at 560 keV. It is difficult to explain

TABLE II. Gamma-gamma coincidence data.

Gamma ray in gate, keV	Gamma rays in coincidence, keV
1630	50
1380	400
1250	160, ~280, 385, 560
1130	~290, 385
1080	160, ~280, 385, 560
960	160, ~290, 385, 560
830	385, 630
750	300, 400
630	385, 500, 830
560	~290, 960, 1080, 1250
500	~290, 385, 630

a peak at about 750 keV appearing in the coincidence spectrum, Fig. 5(b). The coincidences involving the 290-keV gamma ray are analyzed in the discussion. The results from the coincidence studies are summarized in Table II.

D. Beta Spectrum and Beta-Gamma Coincidence

The beta spectrum of Pd^{111} and Pd^{111m} as studied on a scintillation spectrometer using an anthracene crystal ($\frac{1}{2}$ in. thick) showed the highest beta energy in both the cases extending up to 2100 keV. Due to the presence of Pd^{109}, where the 99.97% decay is by beta emission (end point $\sim$1025 keV), it was not possible to separate out the lower energy beta groups from the gross beta spectrum of Pd^{111}. The end points of various beta groups feeding the different energy levels were determined from the beta-gamma coincidence measurements and their intensities were calculated from the gamma-ray intensities. The beta-gamma coincidence measurements were carried out using a purified source of the 5.5-h Pd^{111m} in equilibrium with the 22-min activity, in a similar arrangement as described above except that on one side the NaI(Tl) detector was replaced by an anthracene crystal. The Fermi analysis of beta spectra in coincidence with different gamma rays is given in Fig. 6. The relative intensities of the beta transitions to the various energy levels and their log *ft* values are given in Table III. In this calculation, the intensity of the 160-keV transition was corrected for internal conversion using a theoretical value of α_K.

TABLE III. Intensities of beta transitions calculated from gamma intensities and their log *ft* values.

E (keV)	Daughter level (keV)	Intensity	log *ft*
	(i) 5.5-h activity		
370	1970	0.5%	6.5
530	1810	1.9%	6.6
580	1760	1.8%	6.6
700	1640	1.0%	7.3
1120	1220	1.5%	7.6
	(ii) 22-min activity		
330	1850	1.0%	4.9
670	1515	3.0%	5.6
1165	1015	3.1%	6.0
1620	560	1.7%	6.9
2110	70	84.5%	5.9

III. DECAY SCHEME AND DISCUSSION

The energy levels of Ag^{111} as populated in the decay of Pd^{111} and Pd^{111m} which are consistent with the present data are given in Fig. 7. The Pd^{111m} decays (93.3%) to the ground state by the emission of the 160-keV gamma transition and the rest by beta emission to the different excited states of Ag^{111}. This has been supported by the intense 160-keV gamma ray observed in the decay of Pd^{111m} and the absence of any beta ray in coincidence with this transition. From the systematics in the odd-mass Pd isotopes, the spin and parity of the isomeric state of Pd^{111} appears to be $11/2^-$ while that of the ground state is $\frac{5}{2}^+$.

The ground state of Ag^{111} is known[8] to have spin and parity as $\frac{1}{2}^-$, whereas the 74-sec isomeric state at 70 keV is $\frac{7}{2}^+$. The highest energy level in Ag^{111} is shown at 1970 keV. This level is populated from the decay of Pd^{111m}, as evidenced by the fact that the 1900-keV gamma ray was observed only in this decay and it should be a transition from the 1970-keV level to the $\frac{7}{2}^+$ isomeric state at 70 keV. The next level is at 1850 keV which is based mainly on the 830–630–385-keV cascade as observed in the gamma-gamma coincidence measurements. The 630-keV gamma ray has been observed in coincidence with beta rays extending up to 1170 keV in energy. Hence the 1850-keV level decays partially by the emission of the 830-keV gamma ray to a level at 1015 keV which in turn decays to the 385-keV level through the 630-keV transition.

The 560-keV gamma ray is in coincidence with the 1250-, 1080-, and 960-keV gamma rays. At the same time the beta spectrum in coincidence with the 1080-keV gamma ray extends up to 690 keV, while that in coincidence with the 560-keV ray goes beyond 1150 keV. These results indicate that the 560-keV gamma ray is a transition to the ground state and there are levels at 1810, 1640, and 1515 keV which decay via the energy level at 560 keV. Also since the 1080- and 1250-keV gamma rays are observed only in the decay of Pd^{111m}, the levels at 1810 and 1640 keV are populated in this decay. The gamma ray cascades 500–630–385 keV and 1130–385 keV, as observed in the gamma-gamma coincidences measurement further support the level at 1515 keV. The beta group observed in coincidence with 1440-keV gamma ray has an end-point at 670 keV, thus indicating that the energy level at 1515 keV is fed from the beta decay of the 22-min ground state of Pd^{111}.

The beta spectrum in coincidence with the 1690- and 1640-keV gamma rays, accepted in the same gate, has an end-point at 580 keV (Fig. 6D). This observation indicates an energy level at 1760 keV which is fed from the beta decay of Pd^{111m} and decays to the 70-keV isomeric state and to another state at 120 keV. The observed 1640–50-keV cascade supports the level at 120 keV. The 750-keV gamma ray has been observed in coincidence with a beta group of end-point energy 1120 keV (Fig. 6B) and a gamma ray of energy 400 keV indicating a level at 1220 keV which is being populated from the decay of Pd^{111m}. The 1220-keV excited state decays via the 470-keV level to the isomeric state of Ag^{111}. A 1380-keV transition from the 1850-keV level to this level at 470 keV then explains the 1380–400-keV cascade as observed in gamma-gamma coincidence measurements.

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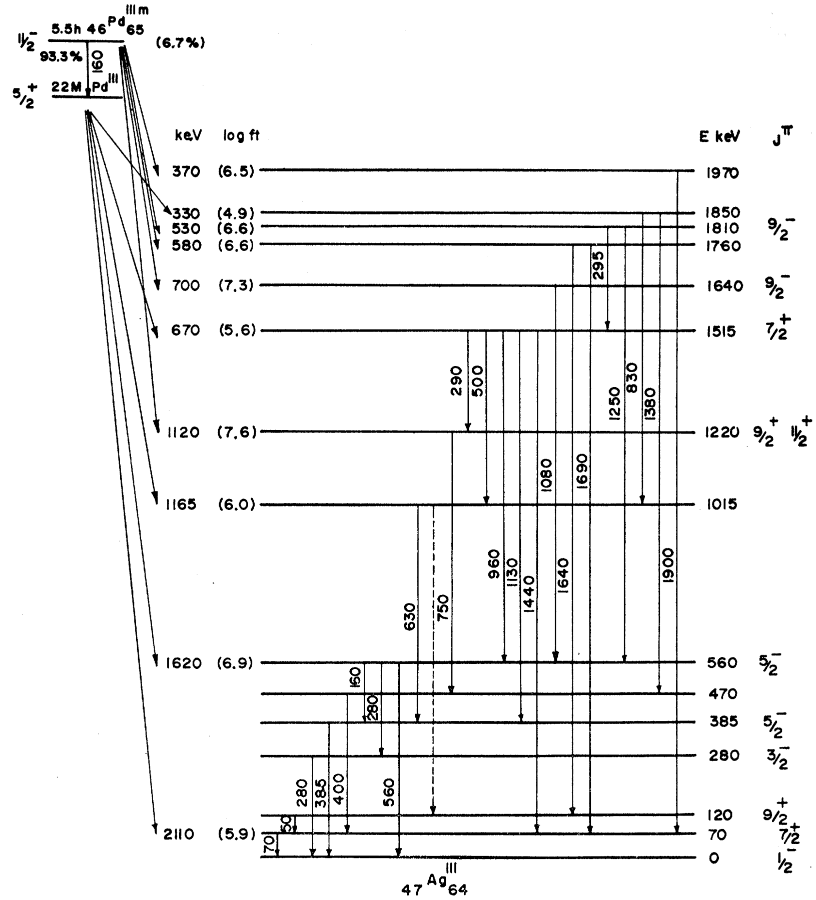

FIG. 7. The energy levels of Ag^{111} from the decay of Pd^{111m} and Pd^{111}.

The analysis of different coincidence spectra has revealed that a gamma ray of energy 290 keV is in coincidence with 1250, 1130, 1080, 960, 750, 560, 500, and 290-keV gamma rays. The systematics of nuclear energy levels in the odd-mass isotopes of silver show a level at about 280 keV. The observed coincidence of the 280-keV gamma ray with the 1250- and 1080-keV gamma rays can possibly be explained by the partial decay of the 560-keV level to a level at 280 keV by another 280-keV transition. Alternatively, one has to assume a level at about 2100 keV to explain the coincidence between 280- and 1250-keV gamma rays. However, there is no evidence in the present work for the existence of such a level at 2100 keV. The coincidence between the 750- and 290-keV gamma rays can be explained by a 290-keV transition from the 1515-keV level. Similarly a transition of 295 keV from the 1810-keV level to the 1515-keV level can explain the 500–290-keV and 1130–290-keV coincidences. The relative intensity analysis has further indicated that there is no beta feeding to the 120-, 385-, and 470-keV levels. It has not been possible to account for the 920-, 450-, and 220-keV gamma transitions as observed in the singles spectra.

The spin and parity assignments to the four low-lying excited states of Ag^{111} at 70, 120, 280, and 385 keV have been made from the systematics of such levels in odd-mass silver isotopes as shown in Fig. 1. It has already been mentioned that in these cases the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ excited states in the energy region of 300 and 400 keV are due to the coupling of the first phonon with the odd proton. The energy levels at 280 and 385 keV in Ag^{111} may be of such nature.

As stated earlier the two levels at 1810 and 1640 keV are populated by the beta decay of $11/2^-$ isomeric state of Pd^{111}. These two states decay via the 560-keV level to the $\frac{1}{2}^-$ ground state of Ag^{111}. Here the total change in spin is 5 and the log *ft* value considerations indicate that $(\Delta I)_{\max}=1$ for the beta transitions to the levels at 1810 and 1640 keV and thus the gamma transitions of energy 1250 and 1080 keV from these levels may be quadrupole in character. The possibility of any octupole transition from the 1810- and 1640-keV levels or from the 560-keV level is unlikely from the consideration of the intensity of the gamma transitions from these levels and also from the absence of their decay to the $\frac{7}{2}^+$ level at 70 keV and $\frac{9}{2}^+$ level at 120 keV. The spins of the levels at 1810 and 1640 keV could be $\frac{9}{2}$ and if it is assumed that they have positive parity then the above-mentioned gamma transitions (1250 and 1080 keV) will be $M2$ in character. In such a situation it will be again difficult to explain the absence of the decay of these two levels by any $M1+E2$ transition to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ energy levels at 70 and 120 keV, respectively. Hence the parity of the levels at 1810 and 1640 keV is likely to be negative and the 1250- and 1080-keV gamma transitions may be $E2$ in character.

The $\frac{5}{2}^+$ ground state of Pd^{111} decays by an allowed beta transition to the 1515-keV level in Ag^{111} as indicated by the log ft value. There is also a gamma transition from the $\frac{9}{2}^-$ state at 1810 keV to this 1515-keV level. Combining these two facts the assignment of spin and parity to the 1515-keV level has been made as $\frac{7}{2}^+$. The present work is inadequate to assign unique values for spin and parity to the other levels.

ACKNOWLEDGMENTS

The authors are grateful to Professor B. V. Thosar and Dr. H. G. Devare for their interest and many helpful discussions. Thanks are also due to Shri K. P. Gopinathan and Shrimati M. Radha Menon for the chemical purification of the source.

PHYSICAL REVIEW VOLUME 140, NUMBER 6B 20 DECEMBER 1965

Decay of Eu^{158}*

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The beta decay of Eu^{158} to levels in Gd^{158} was studied by means of scintillation crystals, beta-gamma, and gamma-gamma coincidence techniques. The sources of the 46 ± 1 min Eu^{158} activities were obtained from the $Gd^{158}(n,p)Eu^{158}$ reaction. As observed in singles and coincidence spectra, the following gamma-ray transitions have been identified: 79.5, 182, 520, 610, 750, 820, composite 950, 1110, 1190, 1260, 1330, 1960, and 2180 keV. The composite 950-, 1110-, and 1190-keV gamma-ray transitions were observed in coincidence with beta particles of kinetic energy greater than 900 keV. Beta-gamma coincidence experiments yielded the maximum energies of the principal inner beta branches as 2520 ± 120, 1950 ± 230, and 1115 ± 90 keV. The ground-state energy difference between Eu^{158} and Gd^{158} has been determined as 3450 ± 150 keV, based on these data. The transition data are shown to be consistent with a decay scheme based on previously proposed levels.

I. INTRODUCTION

The beta decay of Eu^{158} to levels in Gd^{158} was investigated by means of scintillation spectrometers, beta-gamma, and gamma-gamma coincidence techniques, using sources obtained from the fast neutron reaction $Gd^{158}(n,p)Eu^{158}$. The radioactivity of Eu^{158} was first observed and identified in fission fragments by Winsberg.[1] More recently, the beta decay of Eu^{158} was investigated by Daniels and Hoffman,[2] also using sources obtained from fission fragments and from $Gd^{160}(d,\alpha)Eu^{158}$ reaction. Daniels[3] reported the scintillation counter studies of the (45.7 ± 0.5)-min Eu^{158} activity. The scintillation counter and coincidence studies of this laboratory,[4] for the Eu^{158} activity produced by (n,p) reactions, are in good agreement with the results given by Daniels.[3] The levels in Gd^{158} have been previously observed by electron capture decay[5–7] of Tb^{158} in which spin and parity assignments have been determined for levels up to 1190 keV. Neutron capture gamma-ray studies[8,9] have placed levels in Gd^{158} to 3200 keV.

II. SOURCE PREPARATION

The source was prepared by irradiating 400 mg of Gd_2O_3, enriched to 97% in mass 158, with fast neutrons produced at the Indiana University cyclotron as described elsewhere.[10] The Gd targets were wrapped in

* Supported by the U. S. Office of Naval Research, Nonr 1705-(02).
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