Decay of Ag^{103}

A. P. PATRO AND B. BASU
Saha Institute of Nuclear Physics, Calcutta, India
(Received March 7, 1962)

The nucleus Ag^{103} has been studied with scintillation beta and gamma spectrometers. The isotope was produced by a (p,γ) reaction on Pd^{102} with low-energy protons ($\sim$3 MeV) to exclude production of Ag^{104}. In addition to the gamma rays already reported in the literature, prominent gamma rays at 1010 keV, 1160 keV, and 1280 keV have been observed. A new positron group of 1.57-MeV end-point energy has also been observed. Beta-gamma coincidences, gamma-gamma coincidences, and sum studies have been made, and on the basis of those measurements a level scheme of Pd^{103} is proposed.

THE decay of the nucleus Ag^{103} has been previously studied by a number of authors. Enns[1] bombarded palladium foils of natural isotopic abundance with 6-MeV protons and assigned a 73±10-min half-life to Ag^{102} or Ag^{104}. Bendel *et al.*,[2] while investigating Ag^{106} by bombarding palladium with 12-MeV deuterons observed three conversion lines corresponding to gamma energies of 554, 574, and 764 keV, respectively, decaying with a half-life of 66 min which they presumed to be the 73±10-min activity observed by Enns. Halder and Wiig[3] produced an activity of 1.1-h half-life by bombarding silver with high-energy protons (>50 MeV) and assigned it to Ag^{103} by observing its daughter Pd^{103}. They measured the beta spectrum with a survey-type beta spectrometer and observed a 0.6-MeV conversion line and positrons with end-point energy of $\sim$1.3 MeV. Combining these results with those of Bendel *et al.* they proposed a level scheme. Girgis and Van Lieshout[4] produced Ag^{103} by the $Rh^{103}(\alpha,4n)Ag^{103}$ reaction with 50-MeV alpha particles. They observed a gamma ray of 120 keV and a positron group with end-point energy of $\sim$1.2 MeV. Recent work of Ames *et al.*[5] on Ag^{104} has shown that the conversion lines observed by Bendel *et al.* have to be assigned to 69-min Ag^{104} and not to Ag^{103}. Ames *et al.* observed three gamma rays of energy 120, 150, and 265 keV, respectively, and assigned them to Ag^{103}. The spin of Ag^{103} has been measured by Ewbank *et al.*[6] to be $\frac{7}{2}$.

The study of Ag^{103} is made difficult by the presence of Ag^{104} (half-life 69 min and 27 min) when prepared by the usual methods with natural palladium foils. To obviate that difficulty enriched palladium, enriched in Pd^{102} (see Table I), was bombarded with $\sim$3-MeV protons in the internal beam of the cyclotron at the Institute. The low energy of the beam ensures that no Ag^{102} or Ag^{104} is produced by the (p,n) reaction and Ag^{103} is only produced by the $Pd^{102}(p,\gamma)Ag^{103}$ reaction.

TABLE I. Isotopic abundance of the palladium target.

Isotope	Natural abundance %	Enriched sample %
Pd^{102}	0.96	50.9
Pd^{104}	10.97	20.7
Pd^{105}	22.2	13.2
Pd^{106}	27.3	8.4
Pd^{108}	26.7	4.8
Pd^{110}	11.8	2.0

However, due to the low Q value of the reaction $Pd^{105}(p,n)Ag^{105}$ some amount of Ag^{105}(40 day) is also produced; for this reason the bombardment times were kept short to prevent accumulation of Ag^{105} in the target.

The half-life of Ag^{103} has been determined by following the decay of the radiations emitted in a Geiger-Müller counter and an x-ray phosphor. Ag^{103} decays by positron emission and electron capture with a half-life of 66.3±2 min in close agreement with the value obtained by Halder and Wiig.

The radiations emitted by Ag^{103} have been studied by scintillation beta and gamma spectrometers. Figures 1 and 2 show the low-energy and high-energy gamma spectra, respectively, measured with a 7.6-cm diam by 7.6 cm long NaI(Tl) phosphor with a 20-channel pulse-

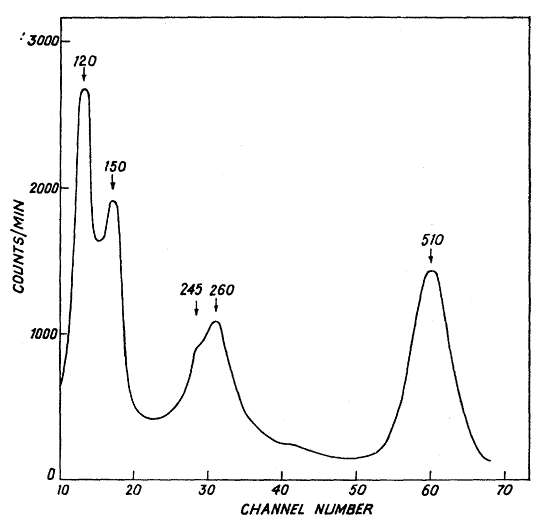

FIG. 1. Gamma spectrum of Pd^{103}. Low-energy region.

[1] T. Enns, Phys. Rev. **56**, 872 (1939).
[2] W. L. Bendel, F. J. Shore, H. N. Brown, and R. A. Becker, Phys. Rev. **90**, 888 (1953).
[3] B. C. Halder and Edwin O. Wiig, Phys. Rev. **94**, 1713 (1954).
[4] R. K. Girgis and R. Van Lieshout, Nuclear Phys. **13**, 493 (1953).
[5] O. Ames, A. M. Bernstein, M. H. Brennan, R. A. Haberstroh, and D. R. Hamilton, Phys. Rev. **118**, 1599 (1960).
[6] W. B. Ewbank, L. L. Marino, W. A. Nierenberg, H. A. Shugart, and H. B. Silsbee, Bull. Am. Phys. Soc. **3**, 370 (1958).

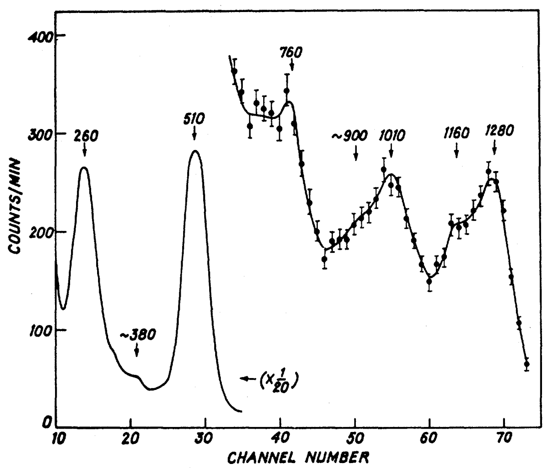

FIG. 2. Gamma spectrum of Pd^{103}. High-energy region.

height analyzer and associated circuits. The source to crystal distance was 10 cm. The gamma spectrum has been followed over two to three half-lives of Ag^{103} and the following gamma rays were observed to decay with the correct half-life: 120±10 keV (26), 150±10 keV (23), 245±20 keV (10), 265±20 keV (34), 380±30 keV (weak), 510±20 keV (100) (annihilation gammas), 760±30 keV (weak), ~900±30 keV (weak), 1010±30 keV (12) (composite) 1160±30 keV (9) and 1280±30 keV (13). The figures in parenthesis following the gamma energies give the relative intensities, taking the annihilation gamma intensity as 100. The errors are of the order of 40%. The 120-keV gamma ray has been observed by Girgis and Van Lieshout, and the 120-, 150-, and 265-keV gammas by Ames *et al.* The 265-keV peak is a composite one, consisting of 245- and 270-keV and possibly 250-keV gamma-ray peaks. The gamma ray of energy 545 keV has not been observed, which confirms that no Ag^{104} has been formed.

Figures 3 and 4 show the low-energy and high-energy gamma spectra (hereafter referred as sum spectra) when the source was placed on top of the 7.6-×7.6-cm

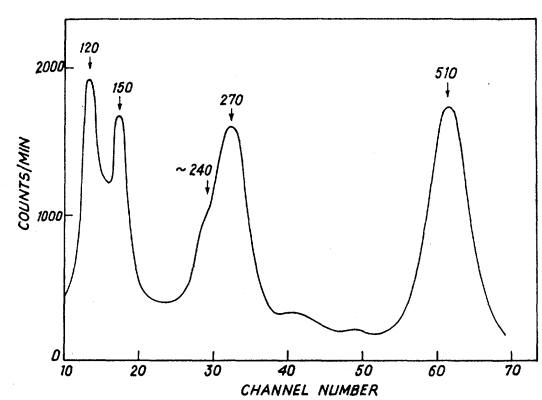

FIG. 3. Sum spectrum of Pd^{103}. Source on top of phosphor. Low-energy region.

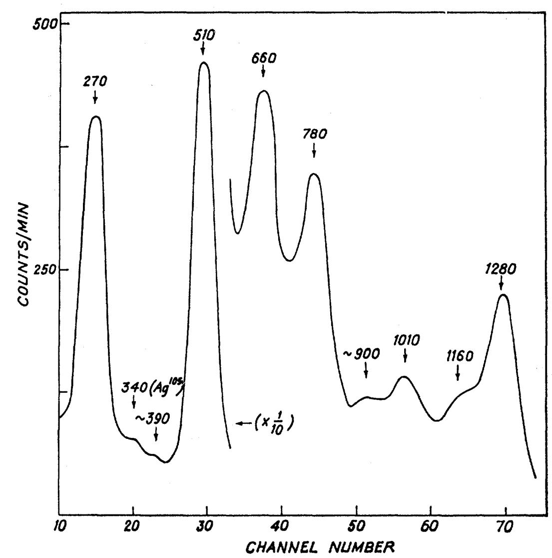

FIG. 4. Sum spectrum of Pd^{103}. Source on top of phosphor. High-energy region.

phosphor. These spectra show new lines due to the summing of the cascade gammas and give some indication of the level positions. We observe two new peaks at 660 and 780 keV which are perhaps due to the sum of 510-keV (annihilation) gammas with either 120- or 150-keV gammas, and of 510-keV gammas with 270-keV gammas, respectively. The highest level appears to be at 1280 keV. The 270-keV gamma peak is enhanced and indicates a level of Pd^{103} at 270 keV.

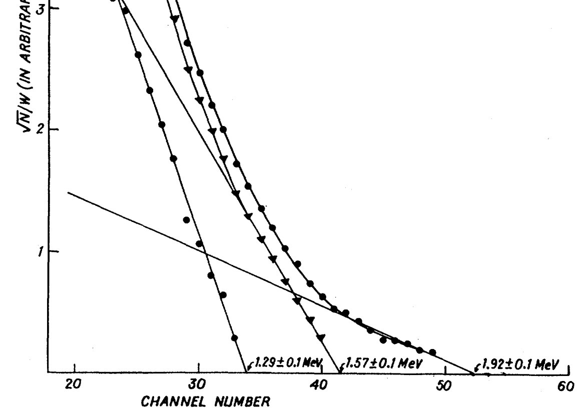

FIG. 5. Kurie plot of beta spectrum of Ag^{103}.

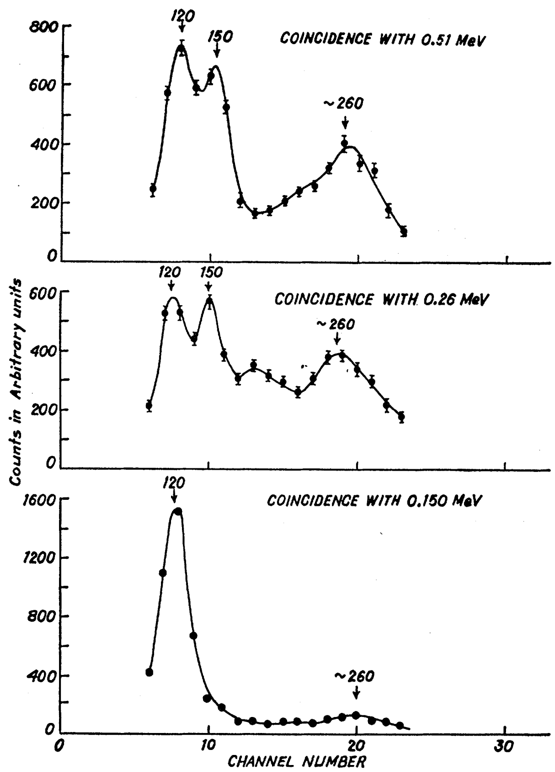

FIG. 6. Gamma-gamma coincident spectrum of Pd^{103}. Low-energy region.

A 10-mg/cm² enriched palladium foil was bombarded with protons and the beta spectrum was measured with a scintillation beta spectrometer. The beta spectrometer consisted of an anthracene phosphor, 3.8 cm in diameter by 1.25 cm long, with a 20-channel pulse-height analyzer and associated circuitry. A Kurie plot of the beta spectrum (Fig. 5) indicates the presence of three beta groups of end-point energies 1.92±0.1, 1.57±0.1, and 1.29±0.1 MeV, respectively. To investigate the low-energy portion of the beta spectrum, a ~2-mg source was prepared by separating silver by conventional procedures. The only beta groups observed were the ones mentioned above. The 1.29-MeV positron group was earlier observed by Halder and Wiig. The 1.92-MeV group is possibly due to the isotope Ag^{106} (24 min) as this portion of the beta spectrum shows a shorter life than 66 min. The 1.57-MeV positron group was not previously reported and perhaps goes to the ground state of Pd^{103}.

TABLE II. Coincidence data.

Gamma energy selected (keV)	Coincident gamma energy (keV)
120	260 (composite), 390, 510, 920, 1010, and 1160
150	120, 260 (composite), 510, 1010
260 (composite)	120, 150, 260 (composite), 1010
510	120, 150, 260 (composite)

From the relative intensities of the 120-, 150-, and 260-keV gamma rays compared to the intensities of the other gamma rays and the energy difference between the positron end-point energies, it appeared probable that the 1.29-MeV group feeds to an excited state at 270 keV. To check this conclusion beta-gamma coincidences were measured selecting the three gamma rays 120, 150, and 265 keV, respectively. The end-point energies obtained from these coincidence studies were

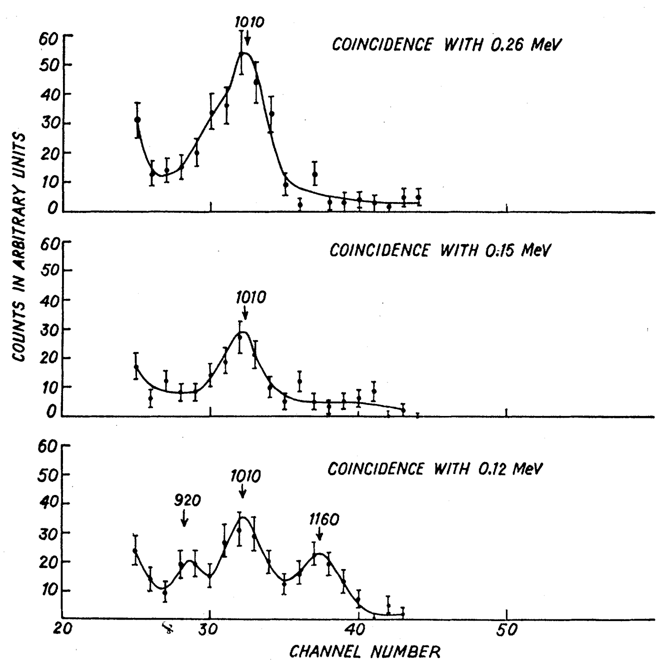

FIG. 7. Gamma-gamma coincident spectrum of Pd^{103}. High-energy region.

1.29 MeV in all cases after correcting for the tail in the positron spectrum due to coincidences through Compton contributions under the gamma peaks. This establishes that the 1.29-MeV positron group feeds to a level at 270 keV and that the two 120- and 150-keV gamma rays are in cascade. It also indicates a level either at 120 or 150 keV above the ground state.

From the sum spectrum it is observed that the highest sum gamma ray is at 1280 keV and the peaks due to the 1160- and 1010-keV gamma rays are depressed compared to the ordinary spectrum. From this it is evident that the highest level of Pd^{103} fed from Ag^{103} is at 1280 keV and the transitions from this level to 270 keV and to a level at 120 keV would account for the other two gamma rays. To elucidate further the cascade relationships between the different gamma rays, gamma-gamma coincidence studies were undertaken.

For coincidence studies the 7.6-×7.6-cm crystal, together with a nonoverloading linear amplifier and single-channel pulse-height analyzer, has been used to select the gamma energy and the coincident spectrum was scanned in a 20-channel pulse-height analyzer gated by the selected gamma pulses. The 20-channel pulse-height analyzer accepted pulses from a scintillation beta spectrometer for beta-gamma coincidence studies, or from a gamma spectrometer using a 3.8-×5.1-cm NaI(Tl) crystal for gamma-gamma coincidence studies.

Figures 6 and 7 show the results of gamma-gamma coincidences and Table II summarizes the results. From these coincidences the conclusions indicated by the sum studies are verified and the 120- and 1160-keV gamma rays are seen to be in cascade; the absence of any coincidence with the 1280-keV gamma ray confirms that the first excited level is at 120 keV. The gamma spectra in coincidence with 120 keV also show the presence of 250-, 380- (this spectrum is not shown), 510- (annihilation gamma rays), 920-, 1020-, and 1160-keV gamma rays. The presence of the 920-keV gamma ray in coincidence with 120 keV, but not with 150 keV, indicates a possible level at 1040 keV and this in turn is able to explain the presence of 245 keV as a transition to this level from the 1280-keV level. The presence of the 380-keV gamma ray in coincidence with 120 keV but not with 150 keV, again suggests a level at 520 keV and this can then account for the 250-keV gamma ray as a transition to the 270-keV level. This level is also indicated by the fairly strong coincidence of the 260-keV gamma ray with the 250-keV gamma ray (Fig. 6).On the basis of the evidence and arguments presented above, a tentative level scheme is drawn up and shown in Fig. 8. From the shape of the 1010-keV photopeak there is some indication of the presence of a gamma ray of energy 1040 keV and this is shown by the dashed line. The region between 500 and 800 keV was not studied by coincidences and hence the position of the 760-keV gamma ray is uncertain. From energy balance it may be either between the 1040- and 270-keV levels or between the 1280- and 520-keV levels. It has been shown between the former levels but it can equally well be placed between the latter ones.

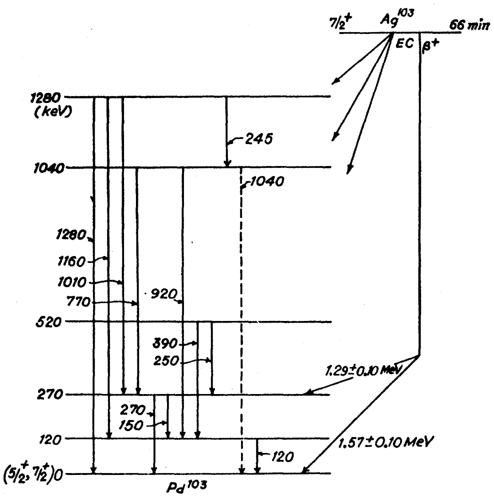

FIG. 8. Level scheme of Pd^{103}.

The authors would like to thank Professor B. D. Nag and Professor D. N. Kundu for their kind interest. Thanks are also due to P. C. Saha and S. C. Saha for their help in irradiating the samples.