Radiations from Cerium-141

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The beta spectrum of Ce^{141} has been examined with an intermediate-image spectrometer adapted for coincidence measurements. The beta decay was found to be complex with two beta groups of maximal energies 574±3 kev and 432±2 kev. The data obtained indicated the presence of a single gamma ray, with an energy of 144.9±0.7 kev. Coincidence measurements inferred that the gamma ray was in coincidence with the lower-energy beta group. Gamma-ray spectra obtained with a scintillation spectrometer and a thin-lens spectrometer indicated that only one gamma ray is present in Ce^{141}. Transitions ascribed to higher- and lower-energy beta groups are $\Delta I=-1$, "yes" and $\Delta I=0$, "yes," respectively. The gamma ray is probably magnetic dipole radiation. An $f_{7/2}$ state, with odd parity, is assigned to the ground state of Ce^{141}; a $g_{7/2}$ state, with even parity, is assigned to the first excited state of Pr^{141}.

AN intermediate-image spectrometer[1] was used to obtain coincidence and total beta spectra. In addition, a photoelectron spectrum was obtained by means of a thin-lens spectrometer.[2] The sources were prepared from 500 mg of Ce metal which had been bombarded by neutrons in the Argonne National Laboratory pile for approximately two months. The Ce metal was kindly supplied by Dr. F. H. Spedding and Mr. David Dennison of this laboratory. The Ce^{143} was allowed to decay for about ten half-lives to Pr^{143} which was then separated from the cerium. A $Zr(IO_3)_4$ scavenging was made to separate impurities, especially Pa^{233} which may be formed in significant quantity if even a small ($<10^{-4}$) part of thorium is present.[3] A source of surface density of about 1.5 mg/cm² was prepared by evaporation from solution on a 0.05 mg/cm² collodion film which was coated with evaporated Al. The film was grounded to prevent charging.

In Fig. 1 are shown the total and coincidence beta spectra of Ce^{141}. The coincidence beta spectrum was obtained by counting only those betas in coincidence with the gamma rays and x-rays detected by a NaI(Tl) crystal placed far enough behind the source to prevent distortion of the beta spectrum by scattering. A few points, with momenta greater than 1.56 m_0c, have been omitted from the graph to facilitate plotting. The two internal conversion peaks shown in Fig. 1 may be attributed to a single gamma ray. In order to check the presence of gamma rays not internally converted, a photoelectron spectrum was obtained with a thin-lens spectrometer.[2] A 12.2-mg/cm² Pb radiator foil was used. In addition to low-energy peaks ascribed to Pr x-rays, two peaks of greater intensity were found and attributed to a single gamma ray. No other peaks were observed up to $2100H\rho$. The energy of the gamma ray, as determined from all measurements made, was found to be 144.9±0.7 kev.

Gamma-ray spectra of purified and impure samples of the source material were obtained with a scintillation spectrometer. The results indicated that a single gamma ray of about 143-kev energy was emitted from the purified source material, whereas from the impure source material two gamma rays were emitted with energies of about 144 kev and 300 kev. The maximal counting rate of the peak corresponding to the gamma ray of 300-kev energy was about one percent of that corresponding to the gamma ray of 144-kev energy.

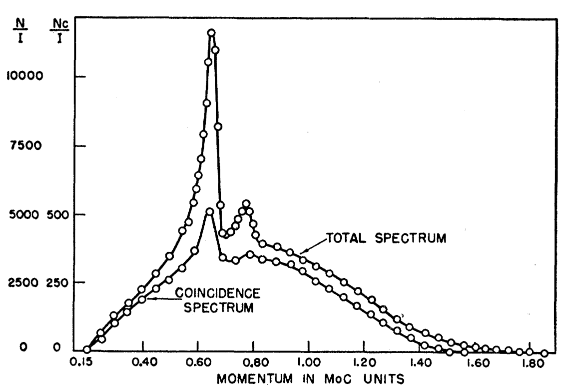

FIG. 1. Total and coincidence beta spectra of Ce^{141}. N and N_c are the number of counts per minute of the total beta spectrum and the coincidence beta spectrum, respectively; I is the current in the spectrometer coil.

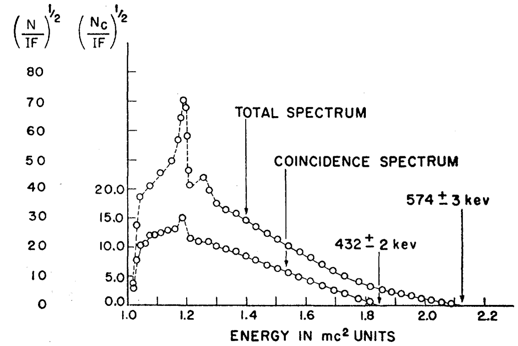

FIG. 2. "Allowed shape" Kurie plots for the total and coincidence beta spectra of Ce^{141}.

[1] Nichols, Pohm, Talboy, and Jensen, U. S. Atomic Energy Commission Report No. ISC-345, 1953 (to be published).
[2] Jensen, Laslett, and Pratt, Phys. Rev. **75**, 458 (1949).
[3] M. S. Freedman and D. W. Engelkemeir, Phys. Rev. **79**, 897 (1950).

TABLE I. Multipolarity of Ce^{141} gamma radiation.

Gamma radiation	α_K [a]	K/L ratio[b]
$E1$	0.08	
$M1$	0.4	7.7
$E2$	0.4	1.4
$M2$	2.6	
Experimental value	0.22	6.4

[a] Obtained by extrapolation from the graphs given by Rose, Goertzel, and Perry, Oak Ridge National Laboratory Report ORNL-1023, 1951 (unpublished).
[b] Approximate values obtained from the figures of reference 7.

A gamma-ray spectrum of a sample resulting from a $Zr(IO_3)_4$ scavenging of the source material was also examined. In addition to a peak of about 143-kev energy, there was found a very prominent peak at about 300 kev. Freedman and Engelkemeir[3] have shown that this gamma ray is probably due to a Pa^{233} activity.

The conclusion can therefore be made that Ce^{141} has only one gamma ray. This is in agreement with the results of Freedman and Engelkemeir[3] and Johansson.[4] From the data of the total beta spectrum shown in Fig. 1, the K/L ratio and K-shell internal conversion coefficient, α_K, were determined to be 6.35 and 0.22, respectively.

Figure 2 shows the "allowed shape" Kurie plots of the total and coincidence beta spectra of Fig. 1. The Kurie plot of the total beta spectrum indicates that two beta groups are present. A least-squares line, drawn for the higher-energy beta group, indicated a maximal energy of 574 ± 3 kev. This least-squares line was extrapolated back to determine the intensities of the two beta groups. The least-squares line obtained from the coincidence beta spectrum indicated that the lower-energy group had a maximal energy of 432 ± 2 kev. The relative intensities of the higher- and lower-energy beta groups were found to be 25 percent and 75 percent, respectively. Based on a total half-life of 32.5 days[3] and graphs given by Feenberg and Trigg,[5] the logft value of the 574-kev beta group is 7.8; the logft value of the 432-kev beta group is 6.9.

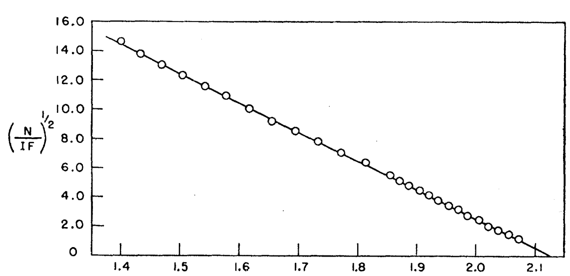

FIG. 3. Kurie plot of the Ce^{141} high-energy beta group obtained by subtracting the low-energy beta group from the total beta spectrum.

[4] S. A. E. Johansson, Arkiv Fysik **3**, 533 (1952).
[5] E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).

Measurements by Engelder[6] indicate a gamma emission lifetime of less than 2×10^{-9} sec. This value limits the gamma polarity to quadrupole or less. The data on the gamma radiation is given in Table I. The experimental value of 0.22 for α_K is consistent with either electric quadrupole ($E2$) or magnetic dipole ($M1$) radiation. The experimental K/L ratio indicates that the gamma ray is probably predominantly $M1$ radiation; of course, the choice of $E2$ radiation is not entirely excluded. The K/L ratio for $E2$ radiation is somewhat more certain than the K/L ratio for $M1$ radiation because more investigations have been made of the former.[7] Ambler *et al.*,[8] on the basis of anisotropic gamma radiation from aligned nuclei, and Heath,[9] on the basis of α_K and K/L determinations, have also concluded that the gamma-ray transition in Pr^{141} is predominantly $M1$ radiation.

The selection rule[7] consistent with $M1$ radiation is $\Delta I=1$, "no." The logft values of the two beta groups are consistent with the selection rules $\Delta I=0, \pm1$, "yes," for the beta transitions. For the ground state of Pr^{141},

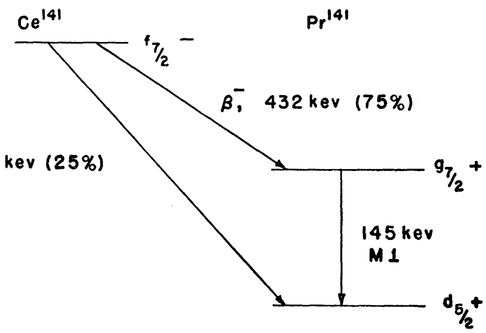

FIG. 4. Decay scheme for Ce^{141}.

a spin of 5/2 has been measured.[10] According to the nuclear shell model,[11] an assignment of $d_{5/2}$, even parity, is given to the ground state of Pr^{141}. For the ground state of Ce^{141} either $h_{9/2}$ or $f_{7/2}$, both with odd parity, is assigned.

The coincidence beta spectrum, shown in Fig. 1, was normalized such that its relative intensity was three times that of the beta spectrum of the higher-energy beta group. By subtracting the normalized coincidence spectrum from the total spectrum, the Kurie plot shown in Fig. 3 was obtained for the higher-energy beta group. The choice of $h_{9/2}$ for the ground state of Ce^{141} demands $\Delta I=-2$, "yes," for the 574-kev beta group. For this type of transition,[12] logft has a value of about 8.5; a logft value of 7.8, obtained for the 574-kev beta group, is apparently too small. Kurie plots correspond-

[6] T. C. Engelder, Phys. Rev. **90**, 259 (1953).
[7] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[8] Ambler, Hudson, and Temmer, Phys. Rev. **95**, 625 (1954).
[9] R. L. Heath, Phys. Rev. **87**, 1132 (1952).
[10] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).
[11] Mayer, Moszkowski, and Nordheim, Revs. Modern Phys. **23**, 315 (1951).
[12] R. W. King and D. C. Peaslee, Phys. Rev. **94**, 1284 (1954).

ing to these transitions have a characteristic "S" shape, which is not apparent in Fig. 3. An $f_{7/2}$ state is therefore assigned to the ground state of Ce^{141}.

The lower-energy beta has a logft value of 6.9 and an allowed shape. A logft value of 6.9 is in the range of $\Delta I=0$, "yes."[12] Such a choice would demand for the gamma-ray transition in Pr^{141} that $\Delta I=1$, "no," consistent with $M1$ radiation. The choice of a $g_{7/2}$ state, with even parity, for the first excited state of Pr^{141} satisfies these requirements.

The tentatively proposed decay scheme for Ce^{141} is shown in Fig. 4. Freedman and Engelkemeir,[3] and Kondaiah[13] have reported somewhat similar decay schemes, with the exception that the former authors concluded that the gamma ray is $E2$ radiation.

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[13] E. Kondaiah, reported in *M. Siegbahn Commemorative Volume* (Almqvist and Wiksells Boktryckeri AB, Uppsala, 1951), p. 411. See also E. Kondaiah, Arkiv Fysik 4, 81 (1952).

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Disintegration of As^{71}

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The disintegration of As^{71}, formed by the deuteron bombardment of separated Ge^{70}, has been investigated with the help of magnetic spectrometers, scintillation spectrometers, and coincidence counting. The half-life was found to be 62 ± 3 hours. Two gamma rays are emitted whose energies are 175.0 ± 0.3 kev and 23 kev. Positrons are emitted which have an end-point energy of 815 ± 10 kev. The state at 175 kev has a half-life of 0.07×10^{-6} sec. A tentative decay scheme is proposed.

1. INTRODUCTION

THE disintegration of As^{71} was first studied by Hopkins[1] who showed that it decayed by electron capture and positron emission to Ge^{71} with a half-life of 60 hours. Mei, Mitchell, and Huddleston,[2] while studying the disintegration of As^{72}, measured an internal conversion line of energy 162 kev having a half-life of 60 hours which they ascribed to As^{71}. Atterling and Thulin[3] made a further study of this isotope. They bombarded germanium metal with 25-Mev deuterons and made an electromagnetic mass separation of the arsenic products. The As^{71} thus produced decays with a half-life of approximately 60 hours. Atterling and Thulin found internal conversion lines corresponding to gamma rays whose energies are 175 kev and 23 kev. They also found one group of positrons with an end point energy of 815 ± 20 kev with a possible indication of a second group at around 300 kev. Stoker and Hok[4] bombarded germanium with deuterons but made no mass separation of As^{71}. Their measurements were therefore made in the presence of other arsenic isotopes. For As^{71}, they found a half-life of 59.5 ± 2 hours, a positron spectrum having an end point at 800 ± 20 kev, and an internally converted gamma ray of energy 175 kev.

The present work stems from the original investigation made in this laboratory by Mei *et al.* Since various arsenic isotopes appear as a result of the bombardment of ordinary gallium with alpha particles or germanium with deuterons, it was decided to use separated Ge^{70} as the target and bombard it with deuterons.

The disintegration of As^{71} is of interest because it decays to Ge^{71} which has 32 protons and 39 neutrons. At 39 neutrons or protons, the $p_{1/2}$ and $g_{9/2}$ states have approximately the same energy, and isomeric transitions should exist. However, out of twenty-one species having 39 neutrons or protons, only four isomeric pairs are known to occur. Nevertheless, it is of interest to look for isomeric states in the disintegration of As^{71}.

2. BETA AND GAMMA-RAY SPECTRUM

The samples were prepared by bombarding germanium oxide, enriched in Ge^{70} (91.4 percent) with 11.5-Mev deuterons from the Indiana University cyclotron. To the material thus prepared, arsenic carrier was added and the germanium and arsenic were then separated from each other and the remainder of the material by the usual methods involving the distillation of the chlorides. The arsenic was then precipitated as the sulfide and used in this form to prepare beta- and gamma-ray sources. Small amounts

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[1] H. H. Hopkins, Jr., Phys. Rev. 77, 717 (1950).
[2] Mei, Mitchell, and Huddleston, Phys. Rev. 79, 19 (1950).
[3] H. Atterling and S. Thulin, Nature 171, 927 (1953).
[4] P. H. Stoker and O. P. Hok, Physica 19, 279 (1953).