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 log*ft* value of 6.9 and an allowed shape. A log*ft* 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.

The authors wish to express their appreciation to Dr. A. V. Pohm and E. W. McMurry for assistance in obtaining part of the data, to J. Powers and Dr. A. F. Voigt for preparation of the sources, and to A. A. Read and the staff of the electronics shop for the design and construction of the electronic equipment.

[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).

PHYSICAL REVIEW VOLUME 97, NUMBER 4 FEBRUARY 15, 1955

Disintegration of As^{71}

William E. Graves and Allan C. G. Mitchell
*Indiana University, Bloomington, Indiana**
(Received November 5, 1954)

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

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[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).

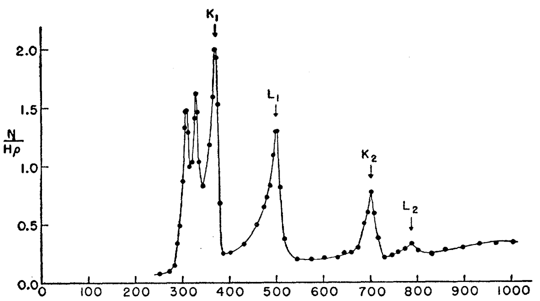

FIG. 1. Low-energy particle spectrum of As activity showing Auger lines and internal conversion lines of As^{71} and As^{73}.

of As^{72} and As^{73} appeared as contaminants and had to be accounted for in any quantitative treatment of the data.

A. The Gamma Rays

The spectrum of the photoelectrons produced by a lead radiator was examined in a magnetic lens spectrometer. Two lines appeared, the annihilation radiation and a line corresponding to a gamma ray of 175.0 kev. The ratio of the intensity of the 175.0-kev line to that of the annihilation radiation was distorted owing to positrons from the contaminant As^{72}. The gamma rays were also observed using a scintillation spectrometer. Here again the annihilation radiation and a line at 175 kev were found. The intensity ratio of the two lines was further distorted, however, since the backscattered peak from annihilation radiation falls at 170 kev.

The particle spectrum was measured in two different instruments: a magnetic lens, in which there was no separation of positrons and negatrons, and a 180° type spectrometer. Figure 1 gives the low-energy portion of the spectrum taken in a magnetic-lens type spectrometer. This spectrum shows Auger lines at 8.35 and 9.45 kev, two lines at 11.85 and 21.6 kev (K_1 and L_1), and two lines of longer period (K_2 and L_2) arising from the 52.5-kev line from As^{73}. The lines at 11.85 and 21.6 kev have a half-life of 62 hours and are K and L internal conversion lines for a gamma ray of 23.00 ± 0.05 kev in As^{71}. The K/L ratio is $\sim$1. Because of window cut-off and Auger line contribution to the K line, a more precise estimate could not be made.

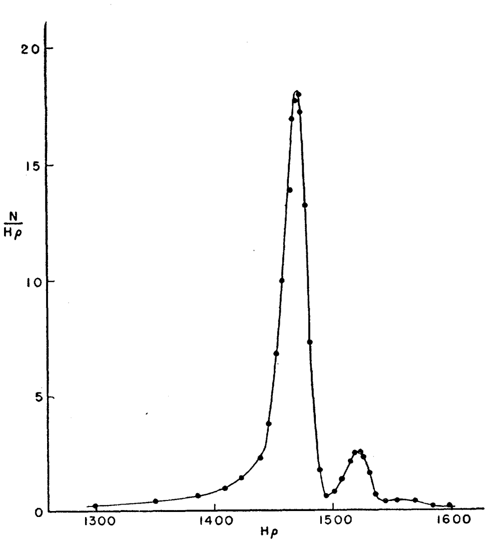

FIG. 2. The internal conversion line of As^{71} at 175 kev.

Figure 2 shows a plot of the internal conversion line corresponding to the 175-kev gamma ray taken in a 180° spectrometer. K, L, and M internal conversion lines can be seen. The energy of the gamma ray computed from all measurements on internal conversion lines is 175.0 ± 0.3 kev and the half-life is 62 hours. The total intensity of the 175-kev internal conversion lines was of the order of 10 times as great as the total intensity of the 23-kev internal conversion lines.

B. The Positron Distribution

The position distribution had to be investigated in the presence of the As^{72} and As^{73} impurities. The more important of these was As^{72} since As^{73} has a long life and was suppressed owing to short bombardment times. The spectrum was investigated both in a magnetic lens and a 180° spectrometer. Figure 3 shows the particle distribution from the active source, with internal conversion lines omitted. The figure shows a high-energy distribution of about 29 hours half-life owing to As^{72} and a 62-hour distribution arising from As^{71}.

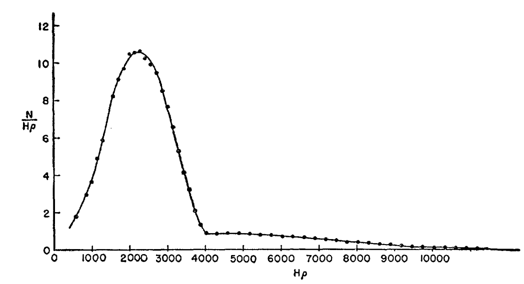

FIG. 3. Particle spectrum (internal conversion lines omitted) from As^{71} (with As^{72} impurity).

In order to determine the distribution arising from the As^{71}, the high-energy distribution was normalized to the distribution of positrons from As^{72}, already determined in this laboratory,[2] and subtracted from the remaining spectrum. A Fermi plot of the result is shown in Fig. 4. The end point of the spectrum comes at 815 ± 10 kev. The points rise above the Fermi straight line below 300 kev, but it is not possible to say, from these data, whether this is caused by another group in As^{71}. The value of log ft for the main transition is 5.73. The characteristics of the disintegration are collected in Table I.

3. COINCIDENCE EXPERIMENTS

In order to get further information about the disintegration scheme, experiments to measure gamma-gamma coincidences were carried out using two scintillation spectrometers equipped with NaI(Tl) crystals and differential pulse-height analyzers. Since the back-scattered peak from annihilation radiation and the 175-kev line overlap, it is clearly impossible to perform coincidence experiments between annihilation radiation and the 175-kev line when the two crystals are in a straight line with the source (180° position). Coincidences were therefore measured between annihilation radiation and the 175-kev line with the two spectrometers at 90°. Figure 5 shows the result when the discriminator of one spectrometer is set on the 175-kev line and the discriminator of the other spectrometer is swept across the spectrum. It will be seen that coincidences exist and hence that positrons are in coincidence with the 175-kev line.

The intensity of the 23-kev line was quite small, indicating high internal conversion and low intensity. For this reason it was not possible to obtain reliable data on coincidences between this line and annihilation radiation.

TABLE I. Disintegration characteristics of As^{71}.

E_γ (kev)	$K:L:M$	$K/(L+M)$		α_K
175.0±0.3	31:4:1	6.3		0.095
23.0±0.05	⋯	1.0		⋯
E_β (kev)			log ft	
815 ±10			5.73	
Half-life	62±3 hours			

Experiments were performed to measure the delay between annihilation radiation and the 175-kev line. For this purpose a fixed delay was placed in the branch which measured annihilation radiation and a variable delay in that measuring the 175 kev. Coincidences were then measured as a function of the variable delay. The results are shown in Fig. 6. The half-life of the state is approximately 0.07×10^{-6} sec. This is very close to the value predicted by the Weisskopf formula for $E2$ radiation. The predicted half-life of $M2$ radiation is about 100 times greater, while other multipolarities seem to be completely ruled out.

4. THE INTERNAL CONVERSION COEFFICIENT OF THE 175-KEV LINE

It is possible to measure the internal conversion coefficient of a line emitted by a positron emitter without recourse to the disintegration scheme if the quantities $(N_e)_K/N_+$ and I_γ/I_a are measured. Here N_+ is the total number of positrons per disintegration, $(N_e)_K$ the number of K electrons per disintegration from the converted gamma ray, and I_γ/I_a the relative intensity of the unconverted gamma ray to that of

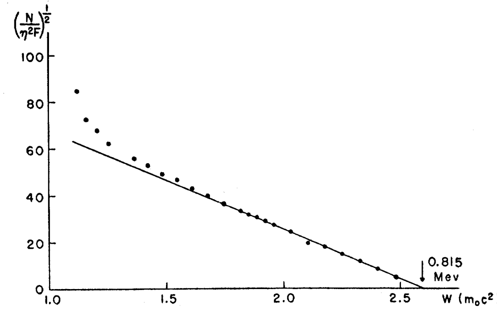

FIG. 4. Fermi plot of positrons from As^{71}.

annihilation radiation. Such a method is subject to the inherent errors in measuring gamma-ray intensities and, in this particular case, trouble arises on account of the As^{72} impurities. It therefore seemed best to make use of some assumptions about the disintegration scheme in order to calculate the internal conversion coefficient.

The assumed scheme is given in Fig. 7 and will be discussed in the next section. The assumptions involved here are that each positron emission or K capture leads to a 175-kev transition, and that positron emission or K capture to a more highly excited state than the one leading directly to the 175-kev transition, being too small to be observed experimentally, can be neglected. In addition it is assumed that any positron group (or K capture) leading to the ground state is forbidden. If one considers the rate of arriving at and leaving the excited state in question, it follows that

$$(N_e)_K+(N_e)_{L+M}+N_\gamma=N_e(1+f_K/f_+),$$

where f_K/f_+ is the ratio of the probability of reaching the excited state leading to the 175-kev transition by K capture to that by positron emission and can be found in tables. From the results of the present experiment $(N_e)_K/N_+=0.227$ and $(N_e)_K/(N_e)_{L+M}=6.3$. In addition, the tables give $f_K/f_+=1.66$. By using the relation given above, the value obtained for α_K is $\alpha_K=0.095$. From the tables of Rose, Goertzel, and Perry[5] the values closest to this are for $E2$ ($\alpha_K=0.082$) and for $M2$ ($\alpha_K=0.105$).

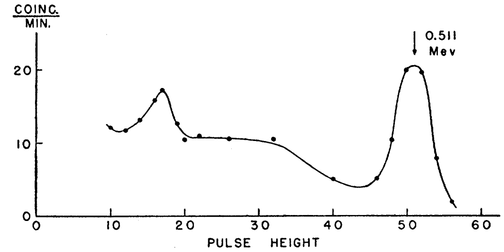

FIG. 5. Coincidences between the 175-kev line and the gamma-ray spectrum.

[5] Rose, Goertzel, and Perry, Oak Ridge National Laboratory Report No. 1023, 1951 (unpublished).

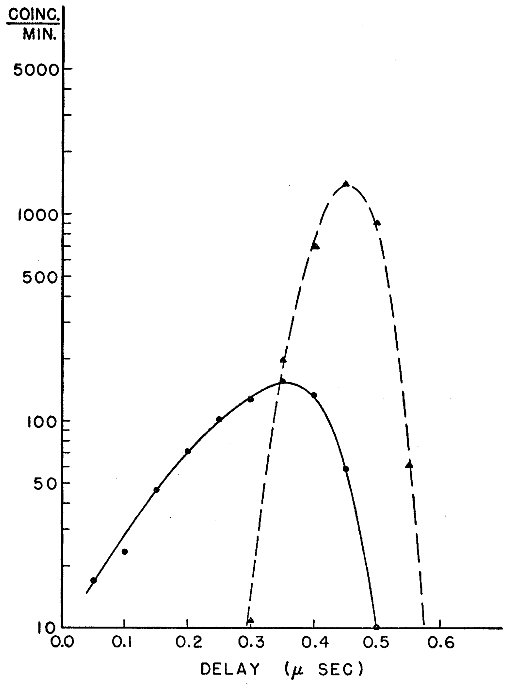

FIG. 6. Delayed coincidences between annihilation radiation and the 175-kev line. Dashed curve gives prompt annihilation-annihilation coincidences for comparison.

The experimental value of α_K for the 175-kev transition, together with the estimate that α_K for the 23-kev transition is high, permits an estimate of the relative intensity of the two transitions to be made. Since the 175-kev internal conversion lines are about 10 times as intense as the 23-kev internal conversion lines, the 175-kev transition (including both conversion electrons and gamma rays) must be about 100 times as intense as the 23-kev transition.

5. DISINTEGRATION SCHEME

It is now possible to draw a tentative disintegration scheme. The experiments of Saraf, Varma, and Mandeville[6] on the decay of the 11-day Ge^{71} to Ga^{71} indicate that the ground state spin of Ge^{71} is $p_{1/2}$. The shell model prediction for the ground-state configuration of As^{71} is either $p_{3/2}$ or $f_{5/2}$. If the decay to the ground state of Ge^{71} is to be forbidden, $f_{5/2}$ must be chosen. Since the main positron spectrum is allowed and appears to lead directly to the excited state from which the 175 kev follows, the first-excited state must have the configuration $f_{5/2}$ or $f_{7/2}$. The former was chosen since the 175-kev line would then be $E2$, in agreement with experiment. The position of the 23-kev line is somewhat more uncertain. This line cannot be $E3$, $M3$, or of higher multipole order since the half-life of the parent state would then be long and inconsistent with the observed decay of the line. In addition, $M1$ and $M2$ seem to be ruled out by the K/L ratio. The assignment in Fig. 7 makes this line an $E1$ transition. This forces a choice of either $7/2+$ or $3/2+$ for the configuration of this state. The configuration $7/2+$ is chosen so that a cross-over transition to the ground state of $E1$ character will be forbidden. The beta decay to this level would then be first forbidden, which would be consistent with the relative intensities of the two lines. Such a weak positron component with an end point differing in energy by 23 kev from that of the main component would not be observed.

The decay scheme as given does not exclude the possibility that a $g_{9/2}$ level lies between the $p_{1/2}$ and the $f_{5/2}$ levels. The beta decay to such a state would be second forbidden, and any gamma rays to a $g_{9/2}$ state could be outcompeted by the two observed ones.

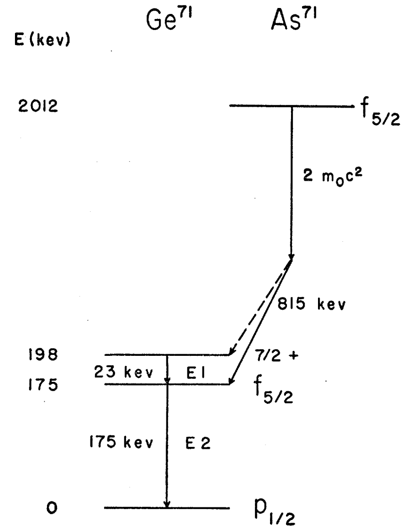

FIG. 7. Tentative decay scheme for As^{71}.

The authors are indebted to Dr. M. B. Sampson and the cyclotron group for making the bombardments, to Mr. A. E. Lessor for making the chemical separations, and to Dr. K. W. Ford for many helpful theoretical discussions. They are also indebted to Mr. T. Lindqvist and Miss E. Hebb for help with some of the experiments. The separated Ge^{70} was obtained from the Stable Isotopes Division of the U. S. Atomic Energy Commission.

[6] Saraf, Varma, and Mandeville, Phys. Rev. **91**, 1216 (1953).