Radiations from Arsenic 77 and Germanium 71*†

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The radionuclide As^{77} has been shown by scintillation spectrometry to emit gamma rays of energies 32, 87, 160, 247, 270, and 520 kev. It is estimated that these quanta are associated with beta-ray branches totaling about 2.5 percent of the total beta radiation. The continuous gamma-ray spectrum accompanying orbital electron capture in Ge^{71} has been shown to have an end point at 225 ± 12 kev. Log ft is calculated to be $4.4(\Delta I=0,\ 1;\ \text{no})$, consistent with an assignment of spin $\frac{1}{2}$ to the ground state of Ge^{71} in accord with the theory of the shell model.

Some data relative to gamma rays from Os^{193} and Ge^{77} are included.

INTRODUCTION

With the advent of scintillation counting, sensitivities of detection have become available for nuclear investigations which make possible the detection of gamma rays of intensity several orders of magnitude less than that previously observable by the earlier methods. Accordingly, it has been decided to reexamine "pure" beta-ray emitters in search of faint gamma radiation. The results of some researches in this direction are presented in connection with the decay of the 40-hr As^{77} along with some measurements relating to the continuous gamma-ray spectrum of the 11-day Ge^{71}.

ARSENIC 77

The beta rays of As^{77} have been shown to have a maximum energy of 0.700 ± 0.007 Mev.[1] Very early measurements[2,3] gave evidence of no detectable gamma radiation. The residual nucleus is Se^{77}, which is also produced[4] by orbital electron capture in Br^{77}. Gamma rays having quantum energies of 160, 237, 284, 298, 520, 641, and 813 kev have been observed[4] to follow K capture in Br^{77}, indicating energy levels in Se^{77} as shown in Fig. 1.

For the purposes of the present investigation, As^{77} was grown from its 12-hr parent, Ge^{77}, when GeO_2 was irradiated by slow neutrons in the Oak Ridge pile. The energy spectrum of the gamma rays of As^{77} as determined from the pulse height distribution resulting from gamma rays on NaI(Tl) is shown in Fig. 2. This distribution was observed on twelve occasions over a time of four half-periods, and the ordinates of the spectrum were found to decay at all points with a half-period of 40 hr, that of As^{77}. Measurements were not commenced until sufficient time had elapsed to make negligible the 12-hr Ge^{77}. Moreover, the measurements on As^{77} were always preceded by a chemical separation of arsenic from germanium. The energies, with an estimated accuracy of five percent, are 87, 160, 247, and 520 kev, with approximate relative intensities of 3, 1, 20, and 6, respectively.

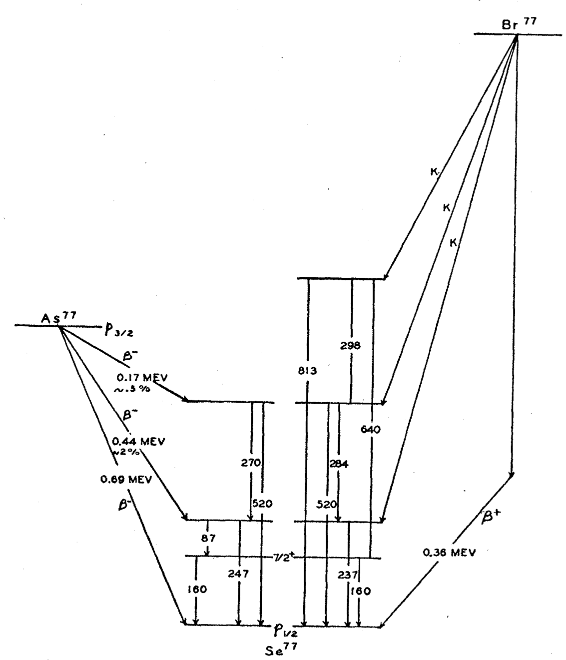

Fig. 1. Disintegration scheme for As^{77} and Br^{77}.

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[1] R. Canada and A. C. G. Mitchell, Phys. Rev. **81**, 485 (1951).

[2] U. S. Atomic Energy Commission Catalog and Price List No. 3, March 1, 1947, September 1, 1947, and No. 3, July, 1949, describe the number of gamma rays emitted by As^{77} as "none." This description may be based upon the measurements of E. P. Steinberg and D. W. Engelkemir, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, New York, 1950), Paper No. 54, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV, who mention no detectable gamma rays from As^{77}.

[3] Mandeville, Woo, Scherb, Keighton, and Shapiro, Phys. Rev. **75**, 1528 (1949), stated in the introduction of their paper that As^{77} emits no gamma rays. This remark was a citation of the comments of reference 2. There are no published data in the paper by Mandeville *et al.* relating to the gamma rays of As^{77}. However, an unpublished beta-ray absorption curve was obtained by Mandeville *et al.* to find the absorption limit, and no gamma-rays were detected in a Geiger counter beyond the beta-ray end point. The present writers could detect several hundred counts per minute, gamma rays from As^{77}, in a Geiger counter shielded from the beta rays in the presence of a relatively intense pile-produced source.

[4] R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 955 (1951).

Gamma-gamma coincidences were measured in two scintillation counters in coincidence. The coincidence rate was noted for various settings of integral pulse-height discriminators in either channel. From the data, it was found that the coincidence rate decreased as the discriminator setting in one channel was increased, until when the discrimination level was greater than the height of pulses in the photoelectric peak of a 270-kev gamma ray, all genuine gamma-gamma coincidences ceased. With both integral pulse-height discriminators set to pass pulses only of height corresponding to 247 kev or more, a considerable number of genuine gamma-gamma coincidences remained, suggesting that the intense 247-kev line is complex. To locate accurately the photoelectric peak of the radiation in cascade with the 247-kev gamma ray, the pulses from either phototube were passed through single channel differential pulse-height discriminators, one set at the photopeak of the 247-kev line. As the base line of the coincident

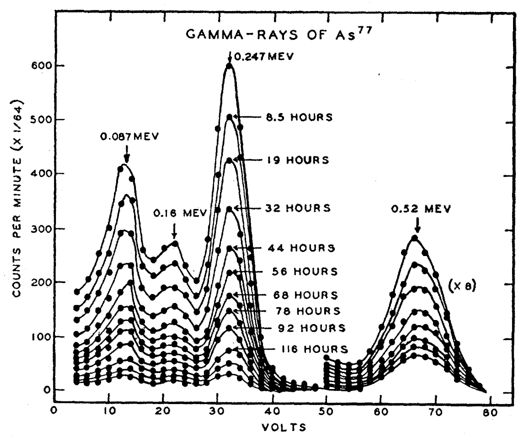

FIG. 2. Pulse-height distribution of gamma rays from As^{77} on NaI-Tl.

differential pulse-height discriminator was raised above 247 kev, the gamma-gamma coincidence rate was found to have a maximum at 270 kev, giving the location in energy of the photopeak of the gamma ray in cascade with the 247-kev line. From the single counting rates in either channel and the gamma-gamma coincidence rate, the intensity of the 270-kev gamma ray relative to that of the 247-kev line was estimated to be two percent. In subsequent measurements, a gamma ray at 32 kev, not shown in Fig. 2, was detected. The gamma ray at 520 kev was found to be noncoincident with the other quantum radiations. The cascade relation between the various gamma rays as indicated by the coincidence experiments is shown in Fig. 1.

The absolute intensity of the beta rays of As^{77} was measured in a thin-walled Geiger counter (window thickness 3 mg/cm^2), and the intensities of the gamma rays were estimated from the areas under the photoelectric peaks and the calculated efficiency of the sodium iodide crystal. From the energies and relative

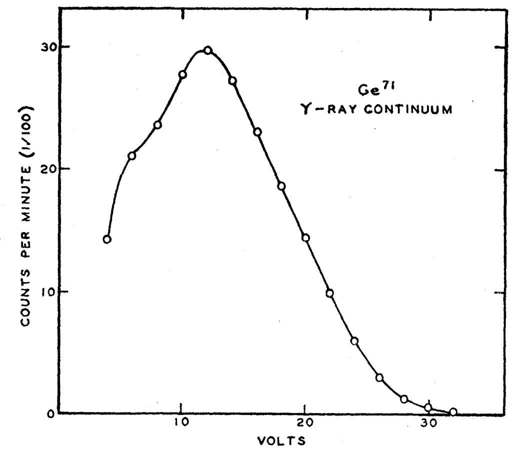

FIG. 3. Pulse-height distribution arising from the gamma-ray continuum of $Ge^{71}+e^{-}\rightarrow Ga^{71}+\eta+\gamma$.

intensities of the gamma rays, the values of log ft for the associated beta-ray spectra were calculated in the order of ascending energy to be 6.6, 7.2, and 5.7, the latter value referring to the beta spectrum leading to the ground state of Se^{77}. Thus, the ground-state transition is allowed, and the remaining two spectra are first forbidden. Beta-gamma coincidences were measurable between the inner spectrum at 0.44 Mev and the 247-kev gamma ray.

As previously indicated, the gamma-ray energy measurements and coincidence data have been combined with those of Canada and Mitchell[4] to give the decay scheme of Fig. 1. As^{75} is known to have a spin of $\frac{3}{2}$. Since As^{77} differs from As^{75} by two neutrons, its ground state orbital is assumed to be $p_{\frac{3}{2}}$ in agreement with the prediction of the nuclear shell model. The spin of Se^{77} has been shown[5] to be $\frac{1}{2}$. Therefore, the beta spectrum at 0.700 ± 0.007 Mev (noncoincident with gamma rays, log $ft=5.7$) is properly characterized by[6] $p_{\frac{3}{2}}\rightarrow p_{\frac{1}{2}}(\Delta I=1$, no). The 160-kev metastable state has been classified[7] as being the initial state of an $E3$ transition with spin $7/2^{+}$. The values of log ft for the two inner beta spectra correspond to ($\Delta I=0$, 1; yes,) ruling out the possibility that either of them terminate at a level in Se^{77} of spin 9/2. Assignment of spins to the remaining excited levels of Se^{77} shown in Fig. 1 is made difficult, because of the great number of configuration levels which can result from $(g_{9/2})^3$.

GERMANIUM 71

The radiations of Ge^{71} have been shown to include no charged particles or monoenergic nuclear gamma rays.[8,9,3] This activity decays solely by orbital electron

[5] S. P. Davis and F. A. Jenkins, Phys. Rev. **83**, 1269 (1941).
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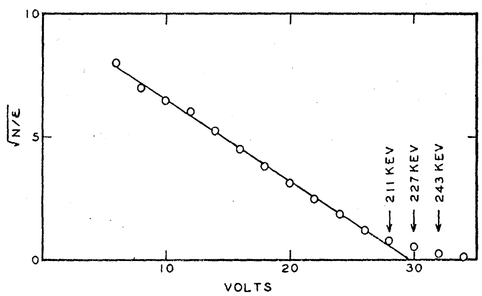

FIG. 4. Fermi plot of the gamma-ray spectrum of Ge^{71}.

capture. It has been shown theoretically[10] that a small fraction of K-capture disintegrations are accompanied by emission of a continuum of quanta and corresponding continuum of neutrinos rather than the usual monoenergic neutrino. Examples of this mode of decay have been found[11,12] in Fe^{55} and in argon 37.[13] Since Ge^{71} decays only by K capture and always to the ground state of Ga^{71}, it was thought to offer an excellent opportunity for the detection of its related gamma-ray continuum. Accordingly, Ge^{71} produced by slow neutron capture in the Oak Ridge pile was studied.

The pulse-height distribution of the continuous gamma-ray spectrum of Ge^{71} is shown in Fig. 3. The Fermi plot of the data of Fig. 3, given in Fig. 4, yields an end point of 225 ± 12 kev. Because of the low specific gamma-ray activity of the source of Ge^{71}, it was necessary to employ a relatively thick, broad, source of irradiated GeO_2. Consequently, the points of Fig. 3 were not corrected for absorption, instrumental resolution, or detection efficiency as a function of gamma-ray energy. The energy of disintegration of Ge^{71} to Ga^{71} by K capture is, of course, equal to the end point of the continuum.

The spin of the ground state of Ga^{71} has been measured[14] and found to be $\frac{3}{2}$. The spin of Ge^{71} is predicted by the shell model[15] to be $p_{\frac{1}{2}}$. From the end point of Fig. 4, $\log ft$ is 4.4, and the transition is allowed ($\Delta I = 0, \pm 1$; no), consistent with the shell model prediction. These interpretations and data are summarized in the decay scheme of Fig. 5.

If the ground-state spin of Ge^{71} is taken to be $p_{\frac{1}{2}}$, the shell model theory indicates that an isomeric level should be present in Ge^{71} of spin $g_{9/2}$, giving rise to an

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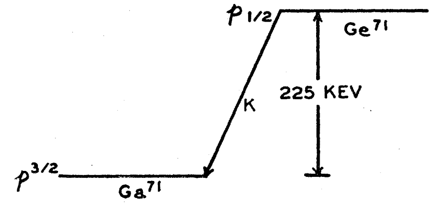

FIG. 5. Decay of Ge^{71}.

$M4$ transition. This gamma ray has apparently not yet been observed.

OSMIUM 193 AND GERMANIUM 77

The gamma rays of Os^{193}($T = 32$ hr) have been studied by Swan and Hill,[16] who find a gamma ray at 72.4 kev. Indications of gamma rays at 215, 323, and 460 kev were reported by them,[16] but they were not definitely assigned to Os^{193}. Very recently,[17] Cork *et al.* have re-examined the gamma rays of Os^{193} and found in a magnetic spectrograph nine lines, ranging in energy from 73 kev to 557.8 kev. Three of these reported gamma rays have also been observed in a scintillation spectrometer by the writers. The measured quantum energies were in the interval 200 kev $< E_\gamma <$ 600 kev at 280, 460, and 560 kev, differing little in energy from the values reported by Cork *et al.*[17]

The gamma rays of Os^{193} were also measured periodically over a time of about 80 hours by the method of coincidence absorption. The hard gamma ray previously reported at 1.58 Mev[18] was again found to be present, but its intensity decayed with a half-period of $\sim$20 hr, suggesting it to be the 1.43-Mev quantum of Ir^{194}.

In the course of studying the gamma rays of As^{77}, the gamma spectrum of the parent element, Ge^{77}, was also noted. The results were essentially the same as those of Smith,[19] except that two high-energy quanta at 2.3 and 2.7 Mev, respectively, unobserved by Smith, were present and decayed in intensity with the 12-hr half-period of Ge^{77}.

ACKNOWLEDGMENT

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[16] J. B. Swan and R. D. Hill, Phys. Rev. **88**, 831 (1952).

[17] Cork, LeBlanc, Nester, Martin, and Brice, Phys. Rev. **90**, 444 (1953).

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