Gamma-Ray Spectrum of As^{77}†

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The gamma-ray spectrum following the beta decay of As^{77} was investigated by means of a scintillation spectrometer. The following gamma-ray energies (in kev) and intensities (quanta per disintegration) were observed: 88(0.003); 155(∼0.002); 243(0.023); 528(0.007). Coincidence experiments show that the 88- and 155-kev lines are emitted in cascade, while the other two lines do not coincide with any other. A level diagram for the product nucleus Se^{77} is suggested.

I. INTRODUCTION AND EXPERIMENTAL ARRANGEMENT

THE isotope As^{77} is known to decay by beta emission with a half-life between 38 and 40 hours and a maximum beta energy near 0.7 Mev.[1,2] Analysis of the electron spectrum failed to show conversion lines.[1,2] Hence it was concluded that, if a gamma radiation is present, it must be very weak. Mandeville *et al.*[3] reported no gamma rays.

A source of As^{77} resulting from the decay of 12-hour Ge^{77} was prepared by a method similar to the one employed by Arnold and Sugarman.[4] The authors are greatly indebted to Dr. G. Friedlander and Dr. W. S. Koski for performing the chemical separation. The arsenic solution, containing a few milligrams of carrier, was finally evaporated on a disk of thin tissue paper 1.5 cm in diameter.

The gamma-ray spectrum was analyzed by means of two scintillation spectrometers which could be used in coincidence. A description of the experimental arrangement was given in connection with a similar investigation.[5] For energy measurements, the 87.5-kev line of Cd^{109}, the 238.6-kev line of ThB, and the annihilation radiation were used as standards. In order to determine absolute intensities of the gamma-ray lines, integral counts of the photoelectric peaks were determined; from the knowledge of the efficiency of the crystal (thickness 1.1 cm), percentage of pulses in the photoelectric peak, and effective solid angle, it is possible to evaluate the number of quanta emitted by the source. To determine its absolute strength, the source on a thin support was suspended in front of a thin-window (2 mg/cm^2) Geiger counter, covered with a diaphragm of known diameter, and counts were taken at different distances. When corrected for absorption in air and the mica window (an absorption coefficient of the beta rays of 22 cm^2/g was assumed), these data showed good proportionality to $1/r^2$ and yielded an absolute strength of 5×10^6 betas per minute at the time when the measurement was performed.

II. ENERGY AND INTENSITY MEASUREMENTS

Preliminary inspection of the pulse-size spectrum on an oscilloscope screen indicated the presence of three well-marked photoelectric peaks and possibly a fourth. Accurate curves were taken by means of a single-channel pulse analyzer. One such curve is shown in Fig. 1, showing photoelectric peaks corresponding to four gamma-ray lines.

It was important to ascertain that these lines were not due to impurities. For this purpose, the decay of each separate line was followed for 3 or 4 half-lives by setting the channel of a scintillation spectrometer to cover the photoelectric peak of the line. All lines decayed with the same period, the average of our determinations being 39 hours, in good agreement with the accepted value. This fact absolutely excludes that any of the reported lines may belong to the parent nucleus, the 12-hour Ge^{77}.

The intensity measurements are satisfactory for the lines at 243 and 528 kev, much less so for the line at 88 kev, and especially for the one at 155 kev, for which neither energy nor intensity could be measured with any accuracy, as it falls between the wings of the

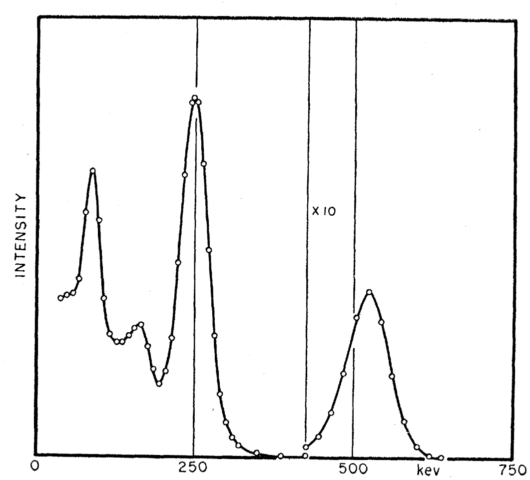

FIG. 1. Pulse-height spectrum from As^{77} showing photoelectric peaks at 88, 155, 243, and 528 kev.

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[1] Jensen, Nichols, and Clement, Phys. Rev. 81, 143 (1951).
[2] R. Canada and A. C. G. Mitchell, Phys. Rev. 81, 485 (1951).
[3] Mandeville, Woo, Scherb, Keighton, and Shapiro, Phys. Rev. 75, 1528 (1949).
[4] J. R. Arnold and N. Sugarman, J. Chem. Phys. 15, 703 (1947).
[5] F. Rasetti and E. C. Booth, Phys. Rev. 91, 315 (1953).

stronger photoelectric peaks of the 88- and 243-kev lines, and is superimposed on the Compton pulses due to the latter. The intensity of the line at 88 kev could not be measured accurately owing to a strong continuum in this region, due to the Compton pulses of the 243-kev line, backscattering of the same by the materials surrounding the source and the detector, and possibly also to brensstrahlung produced in stopping the electrons from the source in a Lucite plate interposed between source and crystal. The energy of the 155-kev line as given does not result from the inaccurate direct measurement, but is deduced as a combination of the 88- and 243-kev lines on account of the coincidence experiments reported later.

The results concerning the energies and intensities of the four lines are summarized in Table I.

III. COINCIDENCE EXPERIMENTS

Possible coincidences between pairs of gamma rays were investigated using two crystal spectrometers connected to pulse-height analyzers. The source was placed between the two scintillating crystals, which subtended large solid angles (of the order of $\frac{1}{5}$ of the total). Other details of the arrangement were previously described.[5] The background coincidence rate, due to cosmic rays plus accidentals, was of the order of a few percent of the rates expected for two coincident gamma rays. No coincidences were observed for the pairs (528, 243), (528, 155), (528, 88), (243, 155), and (243, 88). On the contrary, a high coincidence rate appeared when the two channels recorded the 155-kev and 88-kev lines, respectively. To better establish that these two gamma rays are in cascade, one channel was set to record the 88-kev line, while the spectrum was scanned with the relatively narrow channel. The second spectrometer then recorded a sharp peak in the region of 150 kev, much better defined than in the single-pulse spectrum. Conversely, with one channel set at 150 kev, the other gave a sharp peak near 90 kev.

TABLE I. Energies and intensities of the As^{77} gamma-ray lines.

Energy kev	Pulses in photopeak per minute	Fraction of total solid angle	Efficiency of crystal	Percentage of pulses in photo-peak	Quanta per minute	Quanta per decay
88±2	1140	0.080	1.00	100	14 200	0.0028
155±5	∼600	0.067	0.90	100	∼10 000	∼0.002
243±3	2900	0.060	0.52	80	116 000	0.023
528±5	187	0.060	0.25	36	34 600	0.007

IV. CONCLUSIONS AND DISCUSSION

From the coincidence experiments it is clear that the 88-kev line and the one near 150 kev are in cascade. Since there is a line at 243 kev, whose energy within the accuracy of the measurements is the sum of the two, we assume that the latter represents the cross-over transition and hence assign to the less well-determined line an energy of $243-88=155$ kev. The 528-kev line almost certainly represents an independent transition to the ground state, since it shows no coincidences with any other line; furthermore, it could not lead to a high-excited state, as it involves most of the energy (0.7 Mev) available in the decay.

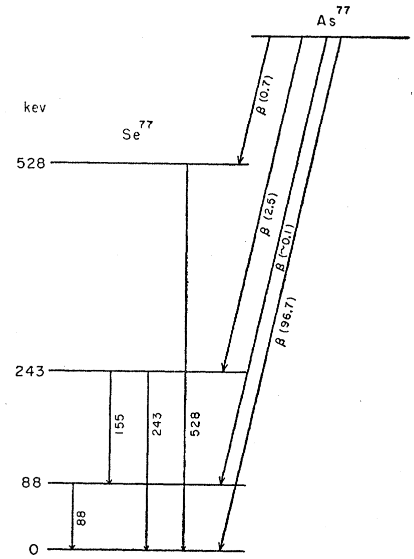

FIG. 2. Decay scheme of As^{77}. Percentage of decay to various levels of Se^{77} is indicated.

On the basis of the reported experimental data, it is possible to construct a complete decay scheme, except for one detail. It is not certain which of the 88-kev and 155-kev transitions precedes the other. If the intensities could be measured more accurately and were found different, the question would be settled, since the second transitions cannot be weaker than the first (the argument applies to the total number of transitions, resulting either in gamma emission or internal conversion; in the present case, the conversion coefficients are probably small, since no conversion lines were observed in the beta-ray spectrum[1,2]). The intensities of the two above-mentioned lines are of the same order of magnitude, and although in the data of Table I the 155-kev line is reported somewhat weaker, this result is by no means certain. Tentatively assuming a greater intensity for the 88-kev line, in the decay scheme of Fig. 2 this line is represented as a transition to the ground state. Approximate numbers of beta rays leading to the various levels of Se^{77} are also indicated. The fact that all these gamma-ray lines are weak explains the fact that As^{77} was previously reported as a pure beta emitter. Transitions to excited levels are also too weak to produce an appreciable distortion of the beta-ray spectrum.