INVESTIGATION OF THE DECAY SCHEME OF As^{76} *BY THE* γ-γ *COINCIDENCE METHOD*

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The decay scheme of As^{76} was investigated with a scintillation coincidence spectrometer. Excited states of Se^{76} were found at 0.56, 1.21, 1.76, 2.42, 2.63 and ~2.85 Mev. Thirteen γ transitions between these levels were detected and their relative intensities were determined.

1. INTRODUCTION

THE decay scheme of As^{76} (T = 26.7 hours) has been investigated by many authors. In reference 1, where the available experimental data are analyzed and an extensive bibliography is provided, Gustova and Chubinskiĭ have shown that the generally accepted decay scheme of As^{76} (see reference 2, for example) is very incomplete and have proposed a new decay scheme, which takes the most recent data into account.[1,3,4] These data are, however, insufficient to determine the decay scheme unambiguously. Excited states of Se^{76}, according to the scheme proposed in reference 1, are so located that gamma transitions with identical or almost identical energies can occur between different levels. Such transitions cannot be resolved in the observed gamma spectrum, which is therefore not amenable to an unambiguous interpretation. The decay scheme given in reference 1 includes levels and transitions that lack direct and reliable experimental confirmation. The relative intensities of many transitions are based only on indirect data (intensity balance), which cannot be regarded as reliable since the intensities of the partial beta transitions have not been definitely determined.

Earlier results obtained by means of γ-γ coincidence studies[5-7] were actually only qualitative since the coincidence spectra were not analyzed and the results were interpreted on the basis of a simplified decay scheme.[2] The γ-γ coincidences studied in the present work have enabled us to establish unambiguously the existence of several excited Se^{76} states and of γ transitions between them. The relative intensities of the transitions were determined through a quantitative analysis of the spectra.

2. APPARATUS, SOURCE, AND EXPERIMENTAL PROCEDURE

We used a coincidence scintillation spectrometer, which was a modification of the instrument described in reference 8. The gamma rays were registered by NaI(Tl) crystals, measuring 4 cm in both thickness and diameter, in conjuction with a FEU-13 photomultiplier. The spectrometer resolution was 9.5% in the analyzing channel and 10.5% in the control channel for the 662-kev γ line of Cs^{137}. Pulses from the single-channel pulse-height analyzer in the control channel and from the integrating discriminator in the analyzing channel were fed to a coincidence scheme with a resolution time $2\tau = 1.5 \times 10^{-7}$ sec. Pulses from the photomultiplier of the analyzing channel were simultaneously fed to a 100-channel analyzer (AI-100-1) triggered by the coincidence circuit.

The efficiency calibration of the spectrometer was based on the total efficiency curves of NaI(Tl) crystals, which were computed in reference 9, and on the experimental ratios of the photopeak area to the area of the entire spectrum for certain gamma emitters with a simple decay scheme in the 150 — 2620 kev region. The resulting photoefficiency curve was verified by measurements with a number of isotopes for which the relative intensities of gamma transitions are well known. These measurements showed that the curve could be used to determine such relative intensities with 5 — 10% accuracy in not too complex spectra. The spectra were resolved with the aid of characteristic curves, from which the line shape for a gamma transition of given energy could be determined. The method of plotting these curves is described in reference 10.

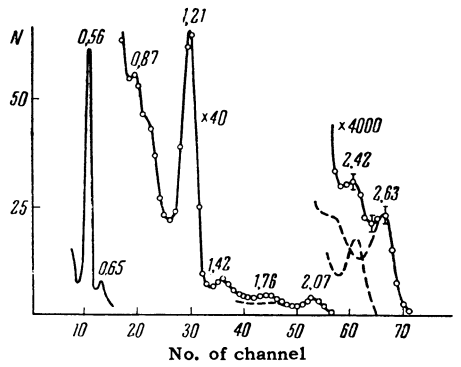

FIG. 1. Gamma-ray spectrum of As^{76}. Energies are given in Mev. Statistical errors for energies under 2.2 Mev are smaller than the size of the circles. Resolution of the hard part of the spectrum is represented by dashed curves. The ordinates are counting rates in arbitrary units.

The As^{76} source was prepared by irradiating arsenic metal with thermal neutrons in a reactor for a period of 40 hours, after which the arsenic was evaporated at about 500° C. Control measurements were performed with a source in which the bombarded arsenic was converted into AsH_3, thus completely eliminating the activity of Sb^{124}, which amounted to less than 1% impurity in the bombarded arsenic.

For coincidence measurements the source was placed between two NaI(Tl) crystals 15 cm apart. A lead absorber 2 mm thick was placed before the crystal of the control channel. Single gamma rays were measured with large distances between the source and crystal (up to 60 cm) in order to eliminate the possible summation of pulses from cascade gamma rays.

3. RESULTS

The gamma spectrum. Figure 1 shows the gamma-ray spectrum of As^{76} which was measured with 50 cm distance between the source and crystal. This spectrum was used to determine the relative intensities of nine gamma lines, which are given in Table I. The 0.56-Mev line was taken as 100.

TABLE I

Energy, Mev	Relative intensity
0,56	100
0,65	13,6±1,5
0.87	0.46±0.09
1.21	12.8±0.7
1,42	1.15±0.10
1.76	0.76±0.11
2.07	1.7±0.15
2.42	0.09±0.03
2.63	0.11±0.03
>2.70	<0.01

Our results for the relative intensities are in good agreement with references 4 and 1. The greatest discrepancies are found in the cases of the 1.42- and 2.63-Mev lines, although the results still agree within experimental error. It should be noted that in references 1 and 4 the existence of a few more weak gamma lines is indicated. We did not detect these lines, but we are not absolutely certain of their nonexistence because it is difficult to resolve the spectra with the required degree of accuracy.

As already mentioned in the introduction, some of the relative intensities in Table I do not correspond to actual gamma-transition intensities since certain lines may include contributions from transitions of equal or nearly equal energy between different levels of Se^{76}, as has been confirmed by investigation of the γ-γ coincidence spectrum.

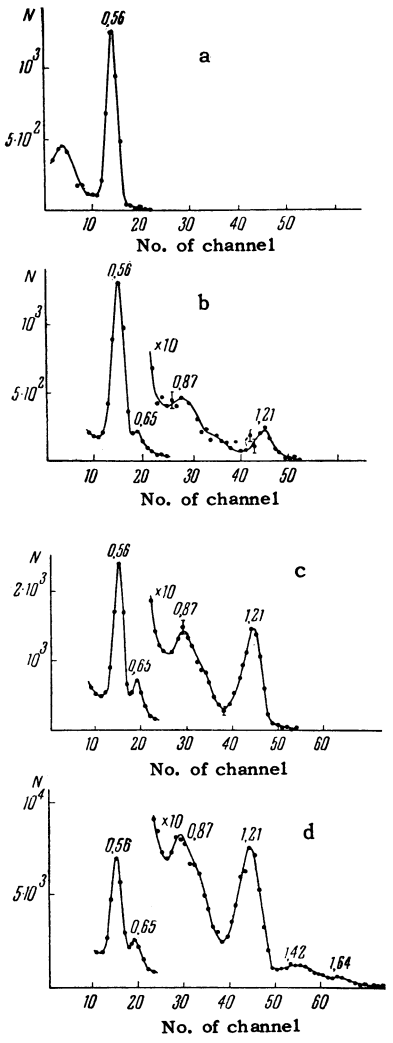

FIG. 2. γ-γ coincidence spectra. Energy ranges defined by the control analyzer window are: a – 2.0 – 2.2 Mev, b = 1.6 – 1.76 Mev, c = 1.4 – 1.5 Mev, d = 1.1 – 1.3 Mev.

γ-γ coincidences. Figure 2 shows the γ-γ coincidence spectra for four window positions of the control channel analyzer. In Fig. 2a the 2.07-Mev transition is in cascade only with the 0.56-Mev transition. Figure 2b shows peaks representing transitions with the energies 0.56, 0.65, 0.87, and 1.21 Mev. Comparison with the preceding spectrum showed that the 0.56-Mev photopeak may be entirely attributed to the 2.07 — 0.56 Mev cascade. Thus the 1.6 — 1.8 Mev gamma rays are in cascade with 0.65-, 0.87-, and 1.21-Mev gamma rays. Figure 2c shows the same peaks with a different intensity distribution. Taking Fig. 2b into account, it can be shown that the 0.87-Mev photopeak results entirely from the 0.87 — 1.76 Mev cascade, and that the 1.42-Mev gamma ray is in cascade with 0.56-, 0.65- and 1.21-Mev transitions. Figure 2d shows photopeaks at 0.56, 0.65, 1.21, 1.42 and ~ 1.64 Mev, all of which represent transitions in cascade with the 1.21-Mev transition.

In addition to the spectra in Fig. 2 we measured coincidences while the analyzer window was set for the 0.56-Mev photopeak. These results confirmed the preceding measurements; specifically, no 0.56 — 1.76 Mev cascade was observed.

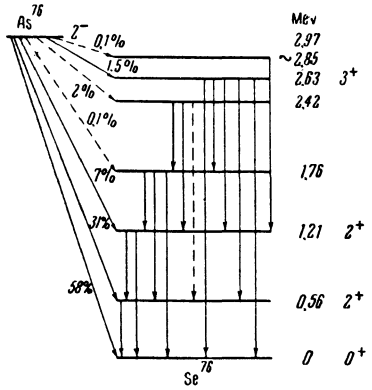

FIG. 3. Decay scheme of As^{76}.

The observed noncoincidence and coincidence spectra can be completely accounted for on the basis of the Se^{76} level scheme in Fig. 3, which will be discussed in the following section. In accordance with this scheme the relative intensities of the 0.87-, 1.42-, 1.76-, 2.07-, and 2.63-Mev transitions can be determined directly from the noncoincidence spectrum; the corresponding lines cannot be accounted for by superposed transitions with nearly identical energies.

When the decay scheme in reference 1 was constructed it was most difficult to determine the 0.56-, 0.65- and 1.21-Mev intensity distribution. These intensities were found by comparing the photopeak areas in the coincidence spectra, using noncoincidence line intensities. For example, by comparing the areas of the 1.21- and 1.42-Mev peaks in Fig. 2d we determined the relative intensity of the 1.21-Mev transition between the 1.21- and 2.42-Mev levels. Similarly, the spectrum in Fig. 2c (using the results in Fig. 2b) yielded the intensity ratio of the direct transition (1.21 Mev) to the 0.65 — 0.56 Mev cascade transition from the 1.21-Mev level to the ground state of Se^{76}; this ratio was found to be 0.85 ± 0.15.

The intensity of the 0.66-Mev transition between the 2.42- and 1.76-Mev levels was obtained from the spectrum in Fig. 2b by comparing the areas of the 0.66- and 0.87-Mev peaks. The relative intensities of other transitions were determined similarly by comparing the photopeaks in the coincidence spectra. For a number of transitions the intensities could be determined by different independent methods, thus providing an additional check on the correctness of the results. Table II shows the relative intensities that we obtained by the described procedure.

4. DISCUSSION

The decay scheme which we propose for As^{76} is shown in Fig. 3. In addition to the previously well known levels of Se^{76} at 0.56, 1.21, and 2.63 Mev (see reference 2, for example) we have introduced levels at 1.76, 2.42, and ~ 2.85 Mev. The 2.85-Mev level is required to account for the observed 1.21 — 1.64 Mev cascade. There is no additional evidence for the existence of this level, from which no ground-state transition was observed. The existence of the 2.42-Mev level is shown by the direct 2.42-Mev transition and the 1.21 — 1.21 and 0.66 — 1.76 Mev cascades. The 1.76-Mev level provides a reasonable explanation

TABLE II

Energy, Mev	Levels, Mev		Relative intensity	Energy, Mev	Levels, Mev		Relative intensity
	initial	final			initial	final	
0.56	0.56	0	100	0.66	2.42	1.76	1.5±0.4
0.65	1.21	0.56	12.1 ± 1.6	1.21	2.42	1.21	3.1 ± 1.0
1.21	1.21	0	10.3 ± 2.1	2.42	2.42	0	0.09 ± 0.03
0.55	1.76	1.21	1.5 ± 0.8	0.87	2.63	1.76	0.46 ± 0.09
1.20	1.76	0.56		1.42	2.63	1.21	1.15 ± 0.10
1.76	1.76	0	0.76 ± 0.11	2.07	2.63	0.56	1.7 ± 0.15
				2.63	2.63	0	0.11 ± 0.03

for the 0.87 — 1.76 and 0.66 — 1.76 Mev cascades without introducing additional levels between 0.56 and 1.21 Mev.

The Se^{76} levels in Fig. 3 enable us to account for all transitions observed by us and for their relative intensities. Our measurements do not indicate the existence of the 2.07-Mev level introduced by Gustova and Chubinskiĭ.[1] Nevertheless, an effort was made to process the data under the assumption that such a level exists. The measurements could not be accounted for when the existence of this level was assumed. If transitions associated with a 2.07-Mev level do exist their intensities are much smaller than the intensities of the transitions represented by the same energies which are shown in Table II.

The experimental data were inadequate to determine the relative intensities of the 0.55- and 1.2-Mev transitions from the 1.76-Mev level. Only their combined intensity could be determined, but the existence of at least one of the two transitions is shown by coincidences between 0.87- and 1.21-Mev photons.

The partial beta intensities in Fig. 3 were not obtained directly in the present work but were computed from the intensity balance of gamma transitions using reliable data for the two hardest components of the As^{76} beta spectrum. The combined intensity of the softer beta transitions obtained in this manner does not disagree with the available very inaccurate experimental data.

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