HARD GAMMA RADIATION FROM As^{76}
THE As^{76} *DECAY SCHEME*

L. V. GUSTOVA and O. V. CHUBINSKII

Leningrad State University

Submitted to JETP editor, June 17, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 1369-1379 (December, 1958)

Measurements were made of the hard γ radiation emitted by As^{76}. Six γ lines were found with energies of 1.21, 1.43, 1.76, 2.08, 2.42, and 2.65 Mev. Their relative intensities were found to be ~ 500, ~ 54, 37, 100, 5.7, and 4.6 respectively. The decay scheme of As^{76} is discussed. It is suggested that the following excited states of Se^{76} exist: 0.56 Mev (2^+), 1.21 Mev (2^+), 1.76 Mev (1.2^+), 2.07 Mev (1.2^+), 2.42 Mev (2.3^+), and 2.64 Mev (3^+). It is also suggested that there may exist states with energies ~ 1.02 Mev and ~ 1.26 Mev (0^+ or 4^+).

1. INTRODUCTION

THE radioactive isotope ${}_{33}As^{76}_{43}$ (T = 26.5 hr) is located between the two stable isobars ${}_{32}Ge^{76}_{44}$ and ${}_{34}Se^{76}_{42}$. The decay of As^{76} to Ge^{76} has not been observed: $\epsilon/\beta^- < 2 \cdot 10^{-4}$; $\beta^+/\beta^- < 10^{-6}$.[1,2]

The decay scheme depicted in Fig. 1 summarizes the results of numerous studies of the β^- and γ emission of As^{76} carried out from 1946 through 1956.[3-13] This scheme agrees satisfactorily with all measurements of β^-, e^-, and γ spectra of As^{76},[3-9,11,13] and of β-γ and γ-γ coincidences and correlations[10-13] that had been reported in publications up to 1956. However, the scheme does not include the 1.76-Mev γ transition observed by some[4-6] but not by others.[9,13]

A comparison of the experimental data obtained by various authors, as well as a discussion of the As^{76} decay scheme, can be found in the final section of this article.

Our aim in studying the hard γ radiation from As^{76} was to determine (1) whether a γ line with $h\nu$ = 1.76 Mev exists, and (2) whether γ transitions with energy greater than 2.1 Mev exist.

2. EXPERIMENTAL ARRANGEMENT AND METHOD

Hard γ radiation from As^{76} was studied by observing recoil electrons in a magnetic spectrometer (γ hodoscope). The construction of the instrument and its spectral properties have been described by B. S. Dzhelepov[14] and O. V. Chubinskii.[15] The energy of a γ ray is determined from the strength of the magnetic field H, the radius ρ of the projected trajectory of the recoil electron (onto a plane perpendicular to H), and from the angle φ between the direction taken by the γ ray and that taken by the emitted recoil electron. The measurements were made under standard conditions: the celluloid target was 150 μ thick, the instrument was filled with a mixture of helium (87%) and methane (13%) to an overall pressure of 30 cm Hg, and the windows of the rectangular Geiger-Müller counters were not covered with film. To minimize the experimental distortion caused by electrons scattered over wide angles in the target, in the counter walls, etc., only those recoil trajectories with small Compton angles φ were included in the results.

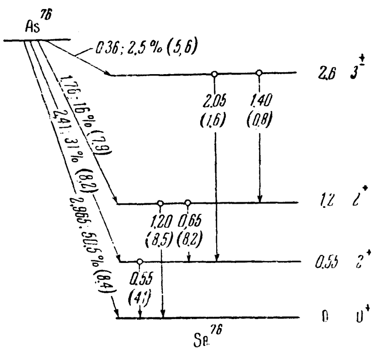

FIG. 1. The As^{76} decay scheme according to data by J. J. Kraushaar and M. Goldhaber[11] and by Kurbatov et al.[13]

For a given magnetic field H, the instrument registers a determined energy interval whose width varies roughly with H (from ~ 1 Mev when H = 500 oersteds to ~ 2 Mev when H = 1000 oersteds). To include all of the spectral region of interest, the γ radiation was measured for different fields with overlapping energy intervals.

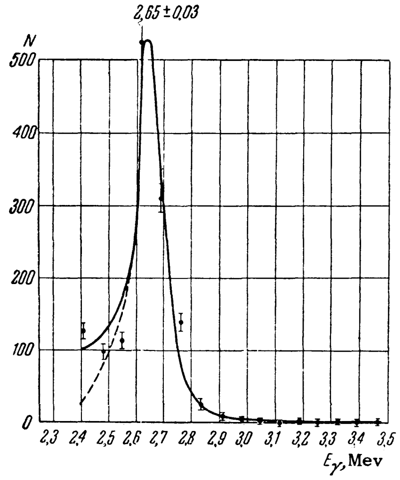

FIG. 2. Measurements of γ radiation emitted by As^{76} when H = 1050 oersteds (As_2O_3 source).

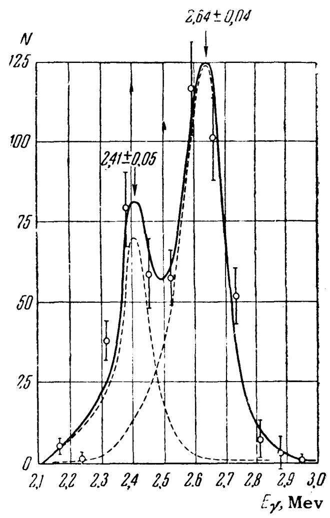

FIG. 3. Measurements of γ radiation emitted by As^{76} when H = 970 oersteds (metallic arsenic source).

3. EXPERIMENTAL RESULTS

Different sources were used to complete several series of measurements. The source for the first experiments was arsenic oxide activated by neutrons. Several γ lines were observed, including some with energies of 2.42 and 2.65 Mev.[2] Control experiments revealed that the As_2O_3 compound used in these measurements was contaminated with Sb^{124} (T = 60 days) and, possibly, with traces of more long-lived activity. The Sb^{124} impurity caused quite a distortion of the As^{76} spectrum in the 1.3 to 2.0 Mev energy region. In the hard part of the γ spectrum ($h\nu > 2$ Mev) the Sb^{124} contribution was considerably less than 1%.

Figure 2 shows the measurements of the γ radiation emitted by As^{76} when H = 1050 oersteds. The line at $h\nu = 2.65$ Mev is quite clearly visible. The counting rate for this line decreased with the corresponding half-life of As^{76} (~ 26 hr).

Pure metallic arsenic was separated from the two contaminated As_2O_3 compounds. The method and complete procedure for the isolation and purification of the arsenic was worked out by M. K. Nikitin. The purity of the metallic arsenic was checked by measuring the γ rays emitted by the radioactive impurities. The contaminant activity of the purified compound was less than 10^{-4} times that of the original compound. Thus, two sources were prepared, each a sealed quartz ampoule containing powdered metallic arsenic (~ 0.4 and ~ 0.7 g) irradiated by slow neutrons. The control measurements showed that these sources did not contain any substantial quantity of long-lived radioactive impurities. Measurements of the γ radiation emitted by the two sources were in agreement. A preliminary report has already been published.[16] Here we discuss the final results.

The quartz ampoule containing 0.72 g of metallic arsenic was 45 mm long and 7 mm in diameter and had an initial activity of $\sim$ 750 mC. During the experiment the magnetic field H was set at 970, 900, 810, 713, 630, 607, and 550 oersteds. The same line was observed at the different values of H, which made it possible to determine more exactly the energies and relative intensities of the γ rays. Figures 3 to 7 show the results of some of the measurements (with the background activity subtracted).

The γ-spectra components were calculated with allowance for the dependence of the instrumental form of the line on $h\nu$ and H. There was good agreement among the γ-ray energies determined from the line maxima for the different values of H. For $h\nu > 1$ Mev we observed six γ lines with the following energies: 2.65 ± 0.04, 2.42 ± 0.05, 2.08 ± 0.03, 1.76 ± 0.04, 1.43 ± 0.05, and 1.21 ± 0.04 Mev.

After the subtraction of the individual lines from the experimental curves, there remained excesses of recoil electrons in the 1.5 to 1.6 and 1.8 to 1.9 Mev regions. Since the statistical errors were rather considerable and the resolving power of the instrument was not great, it may be that these excesses were due to an inaccurate resolution of the spectra into the components.

The relative intensities of the γ lines were determined as follows. The intensity I (in arbitrary units) was computed for each γ line at the different values of H by the formula

$$I = S / W \sum_i A_i t_i,$$

where S is the area beneath the line, W is the probability of registering a γ line for a given H as obtained from the spectral sensitivity curve,

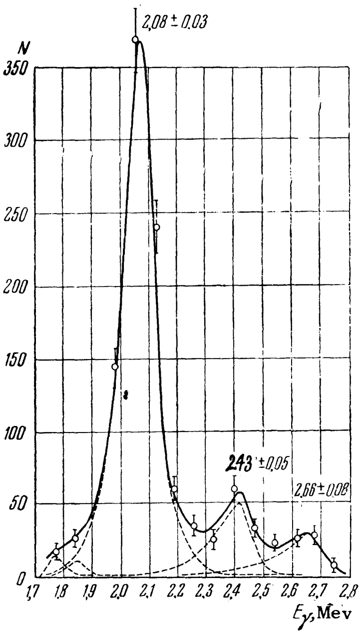

FIG. 4. The same as in Fig. 3, but with H = 810 oersteds.

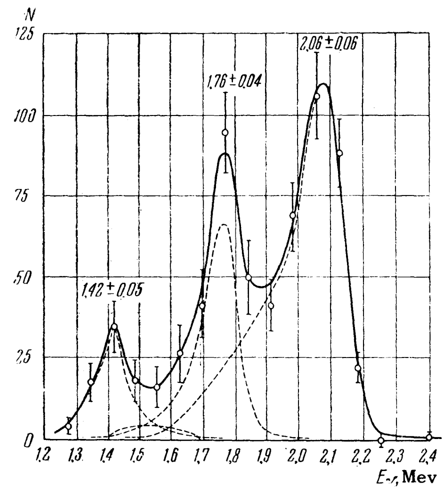

FIG. 6. The same as in Fig. 3, but with H = 607 oersteds.

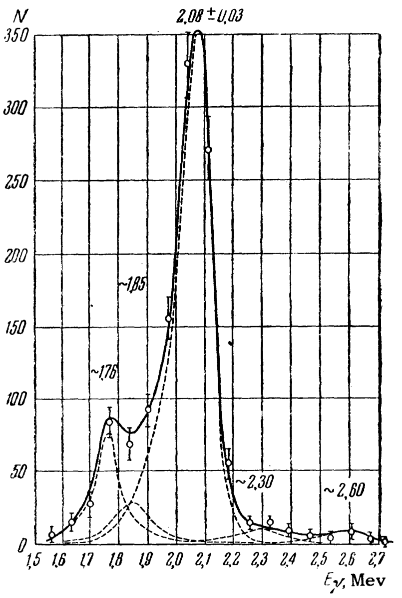

FIG. 5. The same as in Fig. 3, but with H = 713 oersteds.

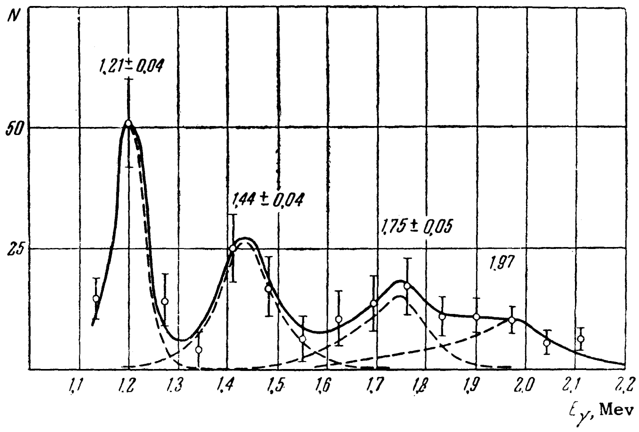

FIG. 7. The same as in Fig. 3, but with H = 550 oersteds.

$\sum_i A_i t_i$ is the so-called effective measurement time for a given H, and A_i is the average activity of the source during the time interval t_i. The intensity unit chosen was that of the 2.08-Mev line, since this line showed good agreement for the different values of H. Table I (column 12) shows the average values of the relative intensities $I/I_{2.08}$ of the γ lines.

The relative intensities of soft γ lines (especially the 1.21 Mev line) are in the nature of approximate evaluations. The probable error in the determination of the relative intensities of the hard γ rays (1.76, 2.08, 2.42, and 2.65 Mev) does not exceed 30%. The fall-off of the 2.65 line on the high-energy side (Fig. 2, 3) permits us to conclude that the γ spectrum of As^{76} apparently has no harder γ lines. If, nevertheless, such γ transitions do exist, their intensity cannot exceed 10% ($h\nu$ = 2.7 to 2.8 Mev) and 1% ($h\nu$ = 2.8 Mev) of the intensity of the 2.65 Mev line.

4. DISCUSSION OF THE MEASUREMENTS AND DECAY SCHEME OF As^{76}

Recent new experiments have broadened and improved our knowledge of the β and γ radiation emitted by As^{76}. Table I summarizes the data on the energies, relative intensities, and multipolarities of γ transitions and on γ-γ coincidences.

Substantially new data on γ radiation from As^{76} is to be found in the 1956 article by Dzhelepov et al.[17] So far this is the only paper reporting the discovery of five new, very weak γ lines in the 0.7 to 1.9 Mev region. To facilitate comparison between the data given in the above article and our data, we have shown in Table I (column 10)

TABLE I

Bair et al.[6] (scintillation spectrometer)	P. Hubert[9] (lens spectrometer)		Kurbatov et al.[13] (scintillation and lens spectrometer)		Grifor'ev, et al.[2,16] (β spectrometer)		Dzhelepov, et al.[17] (riton)			Present data (γ hodoscope)		$\gamma-\gamma$ coincidences, $h\nu$ (Mev)	Multipolarity of the γ transitions
$h\nu$ (Mev)	$h\nu$ (Mev)	$I/I_{0.56}$	$h\nu$ (Mev)	$I/I_{0.56}$	$h\nu$ (Mev)	$I/I_{0.56}$	$h\nu$ (Mev)	$I/I_{0.56}$	$I/I_{2.08}$	$h\nu$ (Mev)	$I/I_{2.08}$		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.58	0.555+0.002	100	0.549±0,004	100	0.553±0,003	100	0.562	100	5130	—	—	1.2[9]; 0.65, 1.4, 2.1[13]; 0.65, 1.2[11]; 2,06[22]	$E2$[7,8,12,16]
—	0.648±0,002	9.5±1	0.643±0,006	20	0,646±0.004	19	0.660	14,3	733	—	—	0,56[10,11,13,22]	$E2(M1<$ $<1\%$)[22] 98%$E2+$ +2%$M1$[27]
—	—	—	—	—	—	—	(0,730)	0.5	26	—	—	—	—
—	—	—	—	—	—	—	(0,870)	0.5	26	—	—	—	—
1,20	1,210±0.005	25±2	1.200±0.006	21	1,206±0,005	18	1.222	12.7	651	1.21±0.04	~500	1.4[13,22,25]; 1,2?[13] 0.56[9]	—
—	—	—	—	—	—	—	(1,400)	0.17	8.7	—	—	—	—
—	1,410±0.006	1,6±0,4	1,402±0,015	2	—	—	1,43	0.8	41	1.43±0.05	~54	0.56. 1.2[13]; 1.2[22,25]	$M1$[22]
—	—	—	—	—	—	—	(1,51)	0.1	5.1	1.5—1.6	10	—	—
—	—	—	—	—	—	—	(1,62)	0,04	2			—	—
1,76	—	—	—	—	—	—	1.765	0.72	37	1.76±0.04	37	—	—
—	—	—	—	—	—	—	(1.85)	0,05	2.6	1.8—1.9	10	—	—
2,02	2,06±0,01	5.5±1	2,053±0,018	4	—	—	2,085	1,95	100	2.08±0.03	100	0,56[13,22]	95%$E2+$ +5%$M1$[22]
—	—	—	—	—	—	—	2,5	0,16	8,2	2.42±0,05	5.7	—	—
—	—	—	—	—	—	—	2,75			2.65±0,04	4.6	—	—

TABLE II

Tomlinson et al.[7,28]		P. Hubert[9]			Kurbatov et al.[13]			Grigor'ev et al.[16]			Pohm et al.[21]	$\beta-\gamma$ coincidences, $h\nu$ (Mev)	Type of β transition
E_r (Mev)	%	E_r (Mev)	%	log ft	E_r (Mev)	%	log ft	E_r (Mev)	%	log ft	E_r (Mev)		
2.98±0,01	52	2,96±0.01	52.5	8,4	2,965	50.5	8,4	2.96±0.02	58	8.3	2.97±0.01	No $\beta-\gamma$ coincidences[9,13]	ΔI=2, yes [7,9 16,21]
2.40±0,03	33	2.40	31.5	8.2	2.41	31.0	8.2	2,41±0,03	28	8.2	2,42±0,01	0.55[13,21]	ΔI = 0, yes [21]
1.76	12	1.75	6.5	8.5	1.76	16.0	7,9	1,76±0,04	7	8.3	1.77±0.02	1.2[13];>0,5[21]	—
—	—	1.20	6	7.5	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	0,88±0,1	3	7.5	—	—	—
0.48	3	—	—	—	—	—	—	—	—	—	—	—	—
—	—	0.35	2,5	5.9	0.36	2.5	5.6	0,35±0.03	4	5.9	—	—	—

their γ-line intensities referred to the 2.08-Mev line as unity.

Our data on the energies and relative intensities of the 1.76 and 2.08 Mev γ lines are in good agreement with the data given by Dzhelepov et al.,[17] but there is considerable discrepancy in the energies determined for the two hardest γ lines. This portion of the γ spectrum was studied with a "Ritron" (for a description of this instrument see Dzhelepov et al.[18]) operated under conditions of increased transmission when the half-width of the experimental lines for $h\nu = 1.76$ to 2.65 Mev amounted to 13.5%. An excess of recoil electrons was observed in the 2.2 to 2.8 Mev region and it was possible to break this excess down into its components in different ways. In particular, the excess was attributed to the existence of two lines with energies of 2.5 and 2.75 Mev.

The conditions of measurement with the γ hodoscope were a good deal more favorable. The half-width of the experimental lines in this energy region amounted to $\sim 6.5\%$, and the 2.42 and 2.65 Mev γ lines stood out quite distinctly (Figs. 2 to 4).

With the new data, the decay scheme for As^{76} has been supplemented as shown in Fig. 8.

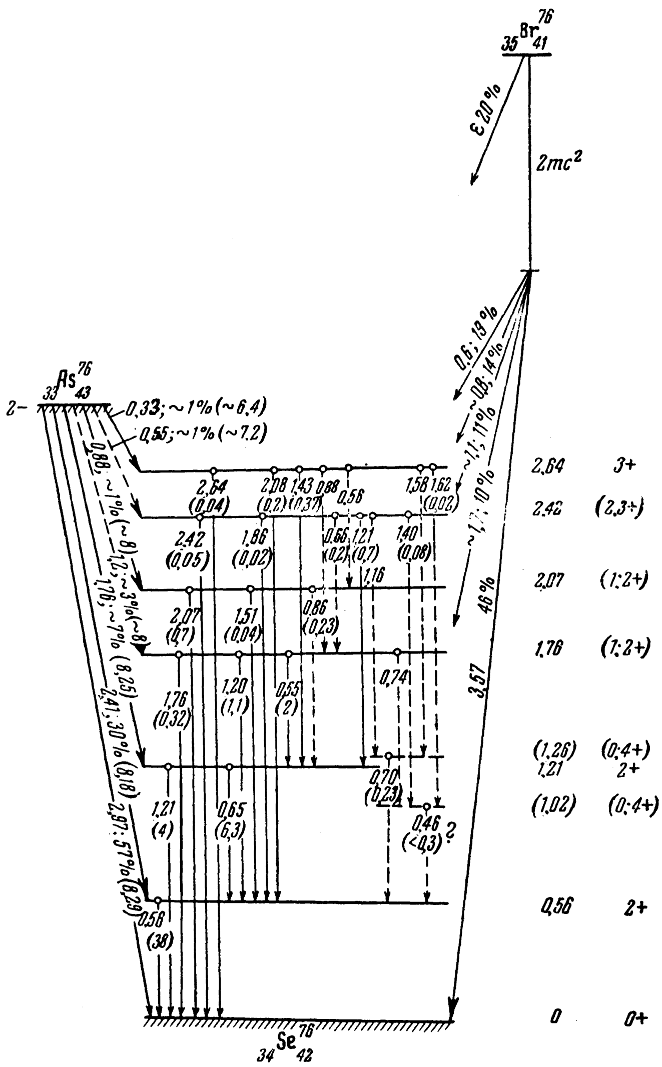

FIG. 8. Proposed As^{76} decay scheme. The energy of the transition from the 2.64 level to the (1.26) level is 1.38 Mev.

Energies and Quantum Characteristics of the Levels

1. The ground state of Se^{76} is of the 0^+ type (even-even nucleus).

2. The ground state of As^{76} is of the 2^- type. This follows from direct measurements of the spin of As^{76},[19,20] as well as from an analysis of the form of the hardest component of the β spectrum ($\Delta I = 2$; yes).[7,9,16,21]

3. The sequence of the first excited levels of Se^{76}, 0 – 0.55 – 1.2 Mev, and their quantum characteristics (0^+, 2^+, 2^+) as represented in our decay scheme of As^{76} (Fig. 1), have been confirmed anew by E. G. Funk Jr. and M. L. Wiedenbeck.[22] Precise measurements[23] indicate that the energy of the first excited level of Se^{76} is 0.5605 ± 0.0003 Mev. The energy of the second excited level is not so accurately known (~ 1.21 Mev).

The first two excited states of Se^{76} possess all the characteristic properties of quadrupole vibration levels of even-even nuclei (the energy ratios, spins and parity, E 2 multipolarity of the $2^+ \rightarrow 2^+$ transition, and the large cross section for Coulomb excitation in the first excited state).[24] In all known cases the intensity of a direct γ transition between a 2^+ two-phonon vibrational level and a 0^+ ground state (for example $h\nu = 1.21$ Mev) is less by a factor of 1.5 to 3 or more than the intensity of a $2^+ \rightarrow 2^+$ transition (for example, $h\nu = 0.65$ Mev). As is known, this experimental fact can be explained within the framework of the generalized nuclear model (the prohibition of a direct transition with a vibrational quantum number change $\Delta n = 2$). So far the only exception to this rule in the region where $A = 58$ to 90 has been Se^{76}; the intensities of the 0.65 and 1.21 Mev γ lines are approximately equal. As will be shown below, it is quite probable that a portion of the γ rays with $h\nu = 1.21$ Mev ($\sim 30\%$) originate in transitions between other levels of Se^{76} (see Fig. 8). The mentioned discrepancy can thus be explained.

4. We have included the 1.76 Mev level to explain transitions with $h\nu = 1.76$ and 0.87 Mev. The presence of a relatively intense transition from the 1.76 Mev level to the ground state of Se^{76} indicates the possibility of spin values of 1 or 2 for this level. There should have been transitions with $h\nu = 0.55$ and 1.2 Mev from the 1.76-Mev level to lower ex-

cited levels. This is experimentally confirmed, albeit by not very accurate data. Thus, P. Hubert[9] bases his conclusion as to the presence of a 1.2 — 0.56 Mev cascade on measurements of γ-γ coincidences. J. J. Kraushaar and M. Goldhaber[11] have observed coincidences involving 1.2-Mev γ rays and the softer γ rays. The counting rate at the single peak as compared with the counting rate at the coincidences for the 1.2 Mev line was considerably greater than might have been expected had the 1.2-Mev line been in a direct cascade with the prominent soft lines. For this reason the authors ascribe the coincidences observed by them to γ rays with $h\nu = 1.4$ Mev and with $h\nu = 0.56$ Mev. However, another explanation of this same experimental fact may be that only some of the γ rays with $h\nu = 1.2$ Mev coincide with those with $h\nu = 0.56$ Mev.

We suggest that there actually exist transitions with $h\nu = 0.55$ Mev and $h\nu = 1.20$ Mev from the 1.76-Mev level. The intensity balance indicates that, apparently, the most intense transition from this level is one with $h\nu = 0.55$ Mev (~ 0.02 quanta per decay), that a less intense transition is one with $h\nu = 1.20$ Mev, and that the weakest transition is one with $h\nu = 1.76$ Mev (~ 0.003 quanta per decay). This intensity ratio for the γ transitions conflicts with the suggestion that the 1.76-Mev level is of a single-particle nature, but the ratio can be satisfactorily explained if this level is assumed to be a three-phonon quadrupole vibrational one with a 2^+ spin. Further evidence in favor of this latter suggestion is the approximate equidistance of the 0.56, 1.21, and 1.76 Mev levels.

5. If a β transition with $E_\gamma \approx 0.88$ Mev exists,[16] a level with an energy of ~ 2.07 Mev and with possible quantum characteristics of 0^+, 1^+, 2^+, 3^+, or 4^+ must be included. In the γ spectrum of As^{76} lines are observed with $h\nu = 2.08$, 1.51, and 0.87 Mev and with a total intensity of $\sim 1.2 \times 10^{-2}$ quanta per decay.[17] These lines can be ascribed to transitions from the 2.07-Mev level. However, the existence of a level at ~ 2.07 Mev cannot be considered proved, because (a) the data on the end-point energy and intensity of the β transition ($E_\gamma \approx 0.88$ Mev) are very inexact, and (b) γ transitions with $h\nu = 2.08$ and 0.87 Mev may occur in other ways (see Fig. 8).

It is known that γ rays with $h\nu = 2.08$ Mev coincide with γ rays with $h\nu = 0.56$ Mev. Heretofore these coincidences have been ascribed entirely to a 2.08 — 0.56 cascade (transitions between the levels $2.6 \to 0.56 \to 0$ Mev). Now, however, another possibility cannot be overlooked, i.e., a 0.56 — 2.08 Mev cascade (transitions between the levels $2.6 \to 2.07 \to 0$ Mev). At the present time it is impossible to settle definitely on either of these two possibilities. If a β transition with $E_\gamma \approx 0.88$ Mev exists and its intensity is on the order of 1%, we are presented with the following logical consequences: (a) the main portion of the γ rays with $h\nu = 2.08$ Mev must be attributable to a $2.07 \to 0$ Mev transition, (b) the intensity of the γ transition between the levels 2.64 and 2.07 Mev ($h\nu = 0.57$ Mev) must be $\le 1\%$, and (c) the most probable spin and parity values of the 2.07 Mev level are 1^+

6. The 2.42 Mev level was included because of two experimental facts: (a) the presence of γ transitions with $h\nu = 2.42$ and 1.85 Mev; (b) the observation of coincidences for γ rays with $h\nu = 1.2$ Mev and $h\nu = 1.2$ Mev.[13] The latter argument cannot be considered to be very rigorously supported, because the accuracy with which the γ-γ coincidences were measured was insufficient for an unequivocal interpretation of the results.

The intensity balance (see below) indicates that some of the 1.21 Mev γ rays are produced, apparently, by transitions between the 2.42 and 1.21 Mev levels. At the present time there are no definite experimental data on the quantum characteristics of the 2.42-Mev level. E. G. Funk and M. L. Wiedenbeck[22] have studied the angular γ-γ correlation between γ rays with $h\nu \ge 1.20$ Mev. These authors attribute their findings to a 1.4 — 1.2 Mev cascade ($2.64 \to 1.21 \to 0$ Mev transitions). The only interpretation not in conflict with the experimental results is that a transition with $h\nu = 1.4$ Mev is purely M1 and that the level ~ 2.6 Mev is of the 3^+ type. If a 1.2 — 1.2 Mev cascade transition exists, this conclusion could obviously be extended to apply also to the 2.42 Mev level. However, it is difficult to reconcile the spin value 3 with the comparatively great probability of a direct $3^+ \to 0^+$ transition ($h\nu = 2.42$ Mev). According to the Weisskopf formula, this transition should be 10^7 times weaker than transitions to the 2^+ levels. If we take this point of view and assume a transition to the 2.42 Mev level to be first forbidden, it appears probable that the 2.42 Mev level is of the 2^+ type.

7. The existence of a level at ~ 2.6 Mev is proved by many measurements of β spectra emitted by As^{76} and of γ-γ coincidences, as well as by the γ transition with $h\nu = 2.65$ Mev reported here. The energy ratios of the γ transitions indicate that the energy for this level is 2.64 to 2.62 Mev. Correlation measurements[22,25] have shown that this level is of the 3^+ type. This fact, as in the case of the 2.42-Mev level, is difficult to reconcile with the presence of a relatively intense direct γ transition to the ground level of

Se^{76}. The hypothesis advanced by Funk and Wiedenbeck[22] that the level at ~2.6 Mev is due to a coupling of a single-particle excitation of the ground state configuration with a two-phonon vibrational excitation provides an explanation for the high probability of a transition with $h\nu = 1.43$ Mev as against the probability of other γ transitions, but this hypothesis makes it even harder to understand why the direct transition with $h\nu = 2.64$ Mev is so intense. It may be that near 2.6 Mev there are two close levels with different quantum characteristics.

8. To find a place in the As^{76} decay scheme for weak γ transitions with energies of 0.73, 1.40, and 1.62 Mev,[17] it must be assumed that still one or two more excited levels of Se^{76} exist. The dotted lines on the right side of Fig. 8 represent two of the possible variants. Inclusion of the 1.02-Mev level makes it possible to explain all three γ transitions. If the 1.02-Mev level is of the 0^+ or 4^+ type and the β transition to it is second forbidden (log ft ≈ 10), then practically the only way in which this level can decay would be by the emission of a γ quanta with an energy of ~0.46 Mev with an intensity of 3×10^{-3} quanta per decay (the total intensity of γ rays with $h\nu = 0.7$, 1.4, and 1.6 Mev). If part of the γ transitions pass through the 1.26 Mev level, the intensity of the 0.46 Mev line will be even less. A line at $h\nu = 0.46$ Mev is at least 130 times weaker than the neighboring one at $h\nu = 0.56$ Mev. It may be that this weak line has thus far escaped notice.

The question of the existence of type 0^+ and 4^+ levels near the 1.21-Mev level is very interesting from the standpoint of verifying the theories behind the generalized nuclear model. According to this model, a two-phonon vibrational level (1.21 Mev, 2^+) should, because of nucleonic interaction, split into close sublevels of the 0^+, 2^+, and 4^+ types. Unfortunately, so far there are too little experimental data to settle this question once and for all.

9. Measurements[26] of the β^+ spectrum of Br^{76} lend some support to the Se^{76} levels presented here. The Br^{76} data make possible at least a qualitative conclusion that Se^{76} has excited levels in the 1.7 to 2, 2.4 to 5, and 2.7 to 3 Mev regions.

Intensity Balance

When the intensity balance condition is considered, discrepancies appear between the data on the relative intensities of the partial β spectra, on the one hand, and the data on the relative intensities of the γ lines on the other. These discrepancies are attributable first of all to inadequate accuracy in the measurements. An intensity balance is made even more difficult because the intense γ lines 0.56, 0.65, 1.21, and 2.08 Mev can be placed differently in the scheme. Let us examine these problems in greater detail.

1. From Table II it is evident that there are some discrepancies among the relative intensities determined for hard β spectra and important discrepancies among the end-point energies and relative intensities of soft β spectra with $E_\gamma \le 1.76$ Mev. However, all the reports are in agreement that the sum of all the β spectra with $E_\gamma \le 1.76$ Mev is no less than 14% of the total number of β transitions.

The article by Grigor'ev et al.[16] differs from the other references in reporting that the authors used a Kurie plot to analyze the spectrum into its components without reference to any decay scheme. Apparently, these are the most objective data available at the present time.

2. The data given by Dzhelepov et al.[17] differ from those given by Chubinskii et al.[2] and by Kurbatov et al.[13] with regard to the values found for the relative intensities of 0.56, 0.65, and 1.21-Mev γ rays.

We used several different assumptions in order to compute the relative intensities of the β spectra and obtained the following results.

(a) If the data on relative γ-ray intensities supplied by Dzhelepov et al.[17] are used, if the intensity of the hardest β spectrum is assumed to range from 52 to 58%, and if the 0.56, 1.21, and 2.08-Mev γ transitions are assumed to occur only at 0.56→0 Mev, 1.21→0 Mev, and 2.64→0.56 Mev respectively, then the sum of the intensities of the β spectra with $E_\gamma \le 1.76$ Mev is 3 to 4 times less than that reported by Grigor'ev et al.[16]

(b) If the same assumptions concerning γ rays are retained and it is further assumed that the sum of the intensities of all the β spectra with $E_\gamma \le$ 1.76 Mev amounts to 14%, we obtain for the β-spectrum intensities the following values:
I (2.97 Mev) = 47%, I (2.41 Mev) = 39%,
I (1.76 Mev) = 11.9%, and ΣI = 2.1% for all the soft β spectra with $E_\gamma < 1.7$ Mev. This is clearly in conflict with the results of Grigor'ev et al.[16]

(c) The discrepancy between the computed and experimental values for the intensities of the two hardest β spectra is reduced if one assumes the 0.56-Mev γ line as found by Dzhelepov et al.[17] to be somewhat more intense than the other γ lines.

(d) The computed and experimental values for β-spectrum intensities are brought into satisfactory agreement if it is further assumed that a small portion (~5%) of the 0.56-Mev γ rays are produced by 1.76→1.21 Mev transitions and that about 30% of the 1.21-Mev γ rays are due to 1.76→0.56 Mev and 2.42→1.21 Mev transitions.

Figure 8 shows approximate values for the intensities of β and γ transitions computed on the basis of the assumptions in (c) and (d) above. The intensity of the hard β transitions and the total intensity of all the soft β transitions with $E_\gamma <$ 1.7 Mev are in good agreement with the experimental data. However, the intensities of individual β components with $E_\gamma < 1.7$ Mev do not coincide with the results obtained by analyzing the β spectrum.

The suggested decay scheme for As^{76} is basically in agreement with the experimental data available at present, but it is not free of all discrepancies. We have attempted to point out the weaknesses in the scheme. It must be stressed that the quantity and, above all, the quality of experimental research have been far from adequate to lead to an unequivocal decay scheme for As^{76}.

The authors express their deep gratitude to L. P. Popovaia and T. V. Poleshchuk for their assistance with the measurements and to M. K. Nitkitin for preparing the sources. We are obliged to B. S. Dzhelepov for his interest in our work and for discussions of the results and to P. P. Zarubin for his opinions on this article.

[1] J. Scobie, Nucl. Phys. **3**, 465 (1957).

[2] Chubinskii, Grigor'ev, Gustova, Zolotavin, Kratsik, Kraft, Poleshchuk, and Iushkevich, Тезисы докладов на VII совещании по ядерной спектроскопии (Reports of the VII Conference on Nuclear Spectroscopy) Acad. Sci. Press, Moscow-Leningrad (1957), p. 24.

[3] L. C. Miller and L. F. Curtiss, Phys. Rev. **70**, 983 (1956).

[4] K. Siegbahn, Arkiv Mat. Astron. Fysik., **A34**, No. 7 (1947).

[5] Wu, Havens, and Rainwater, Phys. Rev. **74**, 1248 (1948).

[6] J. K. Bair and F. Maienschein, Phys. Rev. **81**, 463 (1951).

[7] E. P. Tomlinson and S. L. Ridgway, Phys. Rev. **88**, 170(A) (1952).

[8] F. R. Metzger, Phys. Rev. **86**, 435 (1952).

[9] P. Hubert, Thesis, Paris (1953); Ann. Phys., **8**, 662 (1953).

[10] F. R. Metzger and W. B. Todd, J. Franklin Inst. **227**, 256 (1953).

[11] J. J. Kraushaar and M. Goldhaber, Phys. Rev. **89**, 1081 (1953).

[12] Hamilton, Lemonick, and Pipkin, Phys. Rev. **92**, 1191 (1953).

[13] Kurbatov, Murray, and Sakai, Phys. Rev. **98**, 674 (1955).

[14] B. S. Dzhelepov, Izv. Akad. Nauk. SSSR, Ser. Fiz. **21**, 1580 (1957). [Columbia Techn. Transl. **21**, 1569 (1957)].

[15] O. V. Chubinskii, Izv. Akad. Naul. SSSR, Ser. Fiz. **21**, 1583 (1957). [Columbia Techn. Transl. **21**, 0000 (1957)].

[16] Grigor'ev, Gustova, Zolotavin, Kratsik, Poleshchuk and Chubinskii, Вестник ЛГУ (Bulletin, Leningrad State University), Phys. and Chem. Series, **10**, 37 (1957).

[17] Dzhelepov, Prikhodtseva, Feoktistov and Khol'nov, Izv. Akad. Nauk. SSSR, Ser. Fiz. **20**, 1351 (1956). [Columbia Techn. Transl. **20**, 1245 (1956)].

[18] Dzhelepov, Zhukovskii, and Khol'nov, Izv. Akad. Nauk SSSR, Ser. Fiz. 18, 599 (1954) [Columbia Techn. Transl. **18**, 285 (1954)].

[19] F. M. Pipkin and J. W. Culvahouse, Phys. Rev. **106**, 1102 (1957).

[20] Christensen, Bennewitz, Hamilton, Reynolds, and Stroke, Phys. Rev. **107**, 633 (1957).

[21] Pohm, Waddell, and Jensen, Phys. Rev. **101**, 1315 (1956).

[22] E. G. Funk Jr. and M. L. Wiedenbeck, Phys. Rev. **109**, 922 (1958).

[23] N. Ryde and B. Andersson, Proc. Phys. Soc., **B68**, 1117 (1955).

[24] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1956).

[25] Tor Wiedling, Nucl. Sci. Abstr. **11**, 333 (1957).

[26] S. C. Fultz and M. L. Pool, Phys. Rev. **86**, 347 (1952).

[27] T. Lindqist and I. Marklund, Nucl. Phys. **4**, 189 (1957).

[28] Way, King, McGinnis, and van Lieshout, Nuclear Level Schemes ($40 \leq A \leq 92$), U. S. Atomic Energy Commission, Washington (1955).

Translated by A. Skumanich
295