Van den Bold, H. J.
Van de Geijn, J.
Endt, P. M.
1958

Physica XXIV
23–38

THE DECAY OF THE NUCLIDES ^{75}Se AND ^{75}Ge

by H. J. VAN DEN BOLD, J. VAN DE GEIJN and P. M. ENDT

Fysisch Laboratorium der Rijksuniversiteit, Utrecht, Nederland

Synopsis

Gamma transitions in the decay of the nuclides ^{75}Se and ^{75}Ge have been investigated by scintillation spectroscopy. Single spectra and coincidence spectra were found to conform with the level schemes constructed by previous authors. Directional correlations of five γ cascades have been measured. Polarization correlation measurements were performed on the 121 keV — 280 keV and 136 keV — 265 keV γ cascades. The following spins and parities have been assigned to levels in ^{75}As: ground state $3/2^-$, 199 keV $1/2^-$, 265 keV $3/2^-$, 280 keV $5/2^-$, 304 keV $9/2^+$, 401 keV $5/2^+$.

§ 1. *Introduction*. The nuclides ^{75}Se and ^{75}Ge both decay to stable ^{75}As, the first by electron capture with a half life of 127 days, the second by β^- emission with a half life of 82 min. Investigations of the decay schemes were carried out by Ter Pogossian *et al.*[1]), Cork *et al.*[2]), Jensen *et al.*[3]), Smith, Caird and Mitchell [4]), Schardt and Welker [5]) and Kelly and Wiedenbeck [6]). By these investigations, especially by the latter two, the level scheme of ^{75}As, as it appears in the decay of its two parents, could be considered as well established. The assignment of spins and parities, however, was still a matter of controversy. The aim of the present investigation, which was started in 1955, was directed from the beginning towards the assignment of spins and parities. Some overlap occurs with the work by Schardt and Welker. This is particularly true for the γ intensities and the coincidence spectra and for a part of the directional correlation work. The present work, however, was extended to include the directional correlations of the weaker γ cascades for the measurement of which a special method was developed. A polarization correlation measurement was performed in order to solve the problem of the parity of the 401 keV level in ^{75}As.

§ 2. *Gamma spectrum of the ^{75}Se decay*. The nuclide ^{75}Se was produced by a fortnight's irradiation of samples of ordinary selenium by slow neutrons in the "Jeep" reactor at Kjeller, Norway. It was purified chemically by the radiochemical department of the "Institute for Nuclear Physics" at Amsterdam and delivered as dilute selenic acid. Microliters of this liquid in thin-walled capillary glass tubes have been used as line sources for intensity-, coincidence-, and directional correlation measurements.

The scintillation spectrometers used in this investigation have been described elsewhere [7] [8]. The overall gain was stabilized electronically [9], which allows for accurate measurements of both energy and intensity of the γ transitions. A scintillation spectrum of the γ radiation emitted in the decay of ^{75}Se is given in Fig. 1. In analysing the spectrum photo-peaks were assumed to be of Gaussian shape and an unresolved combination of photo-peaks was treated accordingly. As the γ energies are known from β-spectrometer measurements by Cork *et al.*[2] and by Schardt and Welker [5], it is possible to construct two Gaussian distributions of the correct halfwidth at the correct energies such that their sum fits the experimental pulse distribution. The result of the analysis is indicated in Fig. 1.

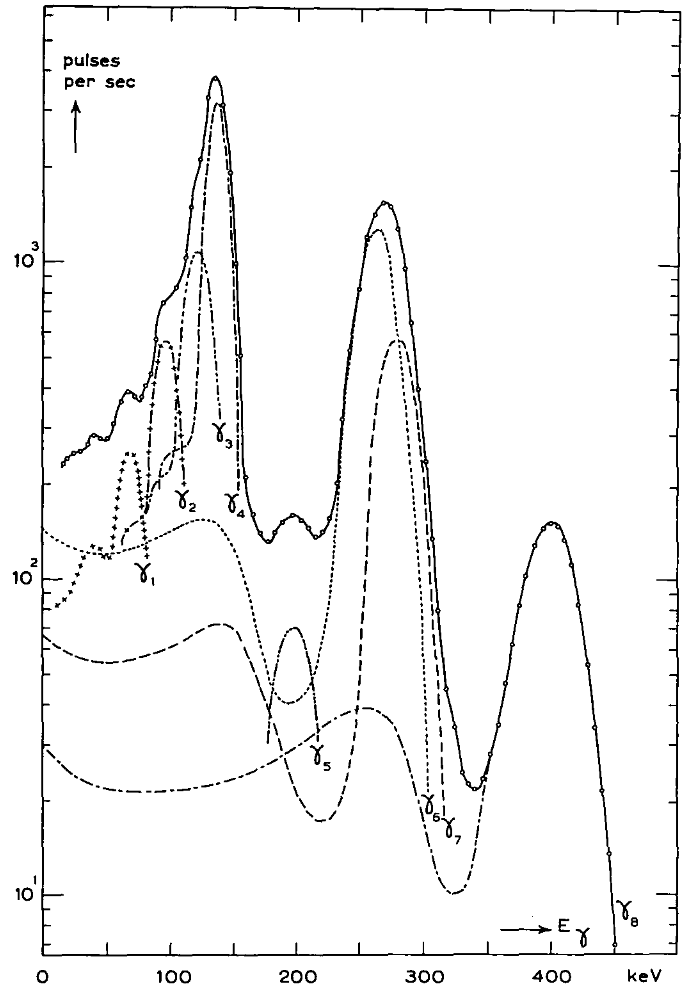

Fig. 1. Analysed scintillation spectrum of the γ radiation emitted in the decay of ^{75}Se.

Sources of ^{203}Hg, ^{198}Au, ^{142}Ce, and ^{22}Na were used for energy calibration. Carefully measured scintillation spectrum energies were found to conform with the β-spectrometer results mentioned above. For intensity measurements the spectrometers were calibrated using sources of ^{203}Hg, ^{22}Na, and ^{137}Cs. The relative intensities thus found are given in Table I. The relative intensities given by Schardt and Welker [5]) have been added for comparison. On the whole the agreement between the two sets of results is quite reasonable. It has not been possible in the present investigation to confirm the existence of an 81 keV γ-transition of which a conversion line was reported by previous authors [5]) [6]).

TABLE I

Relative intensities *) of γ transitions in the decay of ^{75}Se.

Energy keV	Present investigation	Schardt and Welker [5])
γ_1 66	2.1 ± 0.8	1.8 ± 1.0
γ_2 97	5.8 ± 0.6	6.6 ± 1.5
γ_3 121	24.5 ± 3	28 ± 6
γ_4 136	76 ± 5	94 ± 12
γ 199	3.6 ± 0.4	~3
γ_6 265	100	100
γ_7 280	52 ± 5	45.7 ± 4
γt 401	28 ± 2	24.8 ± 2.5
>401	$<10^{-3}$	

*) The intensities have not been corrected for internal conversion.

§ 3. *The γ transitions in the decay of ^{75}Ge.* Radioactive ^{75}Ge, which has a half-life of 82 min, was produced by a (n, p) reaction on ^{75}As. For this purpose arsenic pentoxyde was irradiated with fast neutrons produced in the Philips cyclotron at Amsterdam by the (d, n) reaction on a thick beryllium target. The germanium was separated from the arsenic by destillation of $GeCl_4$ from an oxidizing medium. It was afterwards precipitated as GeS_2. The sources were small pieces of filter paper on which the germanium sulphide had been gathered. The obtained activity was not very strong but the source could be used for measurements lasting nearly two half-lives. The γ radiation was examined using a scintillation spectrometer equipped with a 20 × 20 mm cylindrical crystal of sodium iodide fixed to a R.C.A. 5890 photomultiplier. The observed γ energies and intensities are given in Table II. An analysed γ-scintillation spectrum of ^{75}Ge is given in Fig. 2. Weakness of the source prevented the measurement of coincidences.

§ 4. *Coincidence measurements on γ cascades in the decay of ^{75}Se.* Coincidence measurements were carried out to investigate the decay scheme. The arrangement and the electronic circuits were essentially the same as

TABLE II

Relative intensities *) of γ transitions in the decay of ^{75}Ge

Energy keV	Present investigation	Schardt and Welker [5])
γ_1 66 ± 5	2.5 ± 0.7	2.2
136 ± 5	< 0.3	< 0.15
γ_2 199 ± 10	12.7 ± 1.0	12 ± 1.2
γ_3 265 ± 10	100	100
401	< 0.1	< 0.03
γ_4 420 ± 15	2.6 ± 0.4	2.5 ± 0.7
γ 470 ± 15	2.6 ± 0.4	2.3 ± 0.7
γ_6 620 ± 20	1.3 ± 0.2	1.3 ± 0.3

*) The intensities have not been corrected for internal conversion.

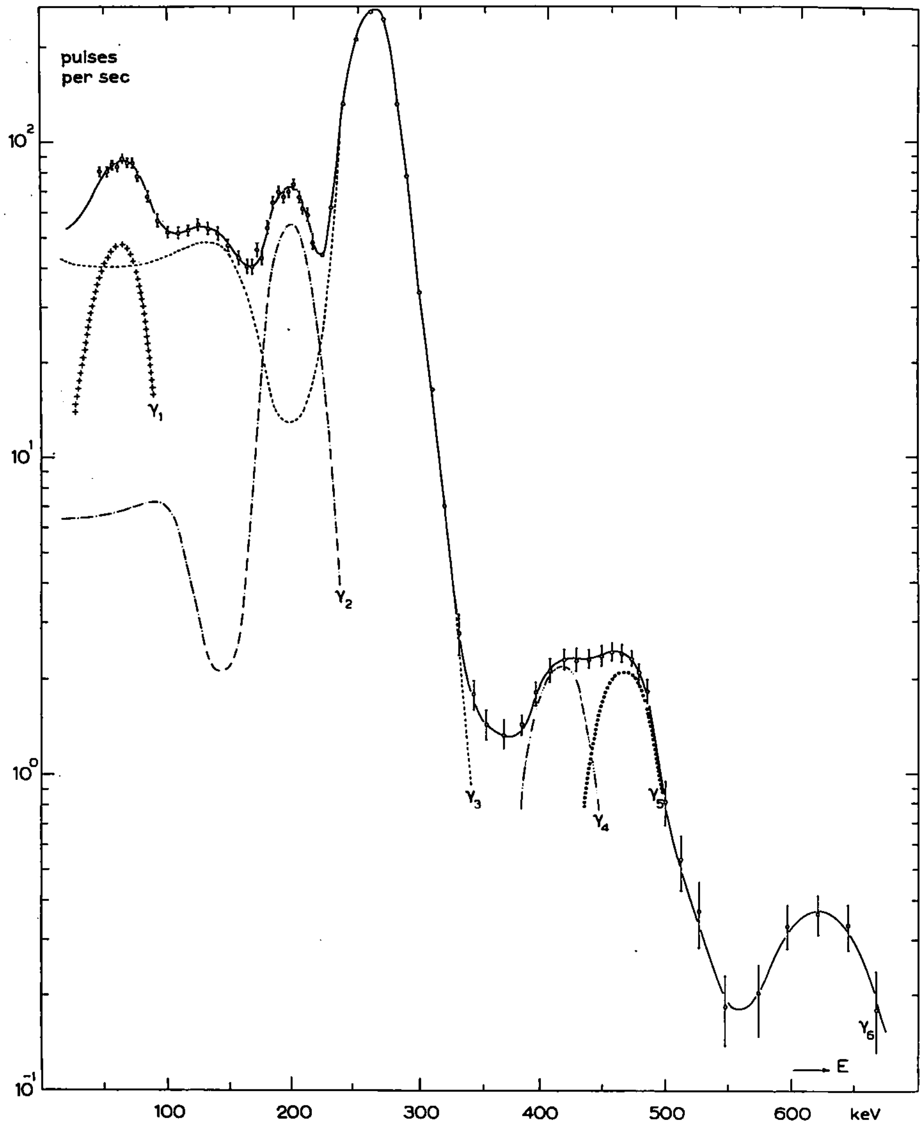

Fig. 2. Analysed scintillation spectrum of the γ radiation emitted in the decay of ^{75}Ge.

described previously [7] [8]). The results are given in Fig. 3, where a single channel spectrum of the lower energy region is given as a reference. From

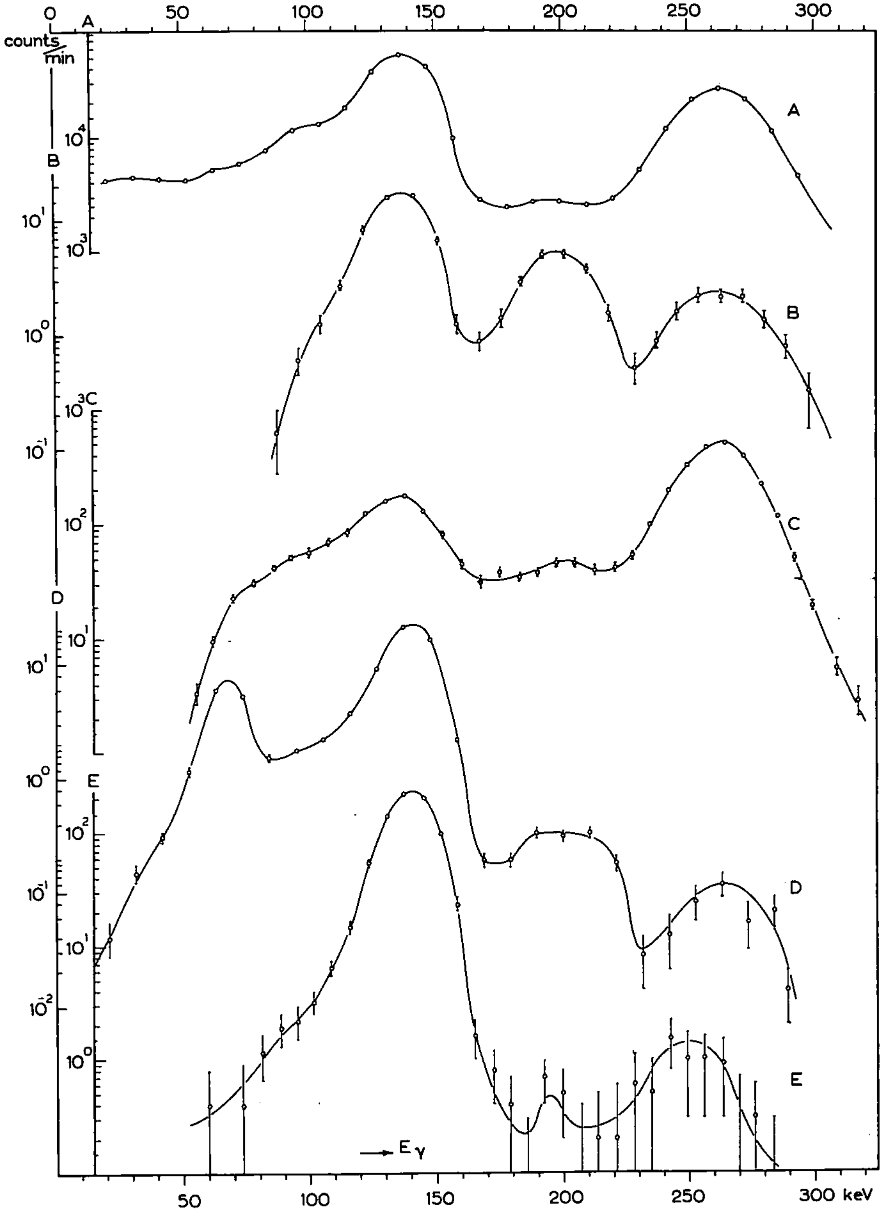

Fig. 3. Coincidence spectra of gamma transitions emitted in the decay of ^{75}Se. The spectrum denoted by A = single channel spectrum below 300 keV, B = spectrum coincident with γ energies between 58 keV and 76 keV, C = spectrum coincident with γ energies between 111 keV and 161 keV, D = spectrum coincident with γ energies between 191 keV and 207 keV, E = spectrum coincident with γ energies between 230 keV and 310 keV.

this figure the existence of the following γ cascades can be concluded: 66 keV–121/136 keV, 66 keV–199 keV, 121/136 keV–199 keV and 121/136 keV–265/280 keV. The 401 keV transition was found to be in coincidence with none of the other transitions. An effort was made to measure the half-life of the 401 keV level by delayed coincidence technique. As the resolving time (0.03 μsec) of the circuit used was not short enough, only an upper limit of 0.01 μsec could be set for the half-life of the level. As a preliminary to the directional correlation measurement of γ cascades quantitative coincidence measurements were carried out to determine the relative intensities of the gamma cascades in the decay of ^{75}Se. In these measurements wide discriminator channels were used and two channels in coincidence were always set to accept photopulses from one of the possible cascades in the decay scheme of ^{75}Se. The relative contribution to the coincidence rate from other cascades at such a channel setting was calculated in the way described in the Appendix to this paper. The following cascades were taken into consideration: 66 keV–136 keV (γ_1, γ_4), 66 keV-199 keV (γ_1, γ_5), 121 keV–199 keV (γ_3, γ_5), 136 keV–199 keV (γ_4, γ_5), 121 keV–280 keV (γ_3, γ_7), 136 keV–265 keV (γ_4, γ_6). From the coincidence counting rates obtained in measurements with the channel pairs set successively on the photo-peaks of all the contributing cascades, it is possible to determine the relative coincidence rate caused by the photo-peaks of the cascade transitions. This calculation, the outline of which is given in the Appendix, involves the solving of six linear equations in six unknowns and a least-squares determination of the errors. From the photopeak contribution to the relative cascade intensity that intensity was determined making use of the known photopeak detection efficiencies of the spectrometers and of the directional correlations determined in § 5. Internal conversion has not been taken into account. The results are given in Table III. Apparently no 121 keV–199 keV cascade occurs. The 97 keV–304 keV cascade is known to proceed via a metastable level [11] [12] [13], and consequently does not contribute any prompt coincidences.

TABLE III

Relative intensities *) of γ cascades in the decay of ^{75}Se			
66 keV — 136 keV:	1.5 ± 0.4	121 keV — 280 keV:	25.6 ± 3
66 keV — 199 keV:	1.6 ± 0.2	136 keV — 199 keV:	4.6 ± 1.0
121 keV — 199 keV:	—0.9 ± 0.7	136 keV — 265 keV:	100

*) The intensities have not been corrected for internal conversion.

§ 5. *Directional correlation measurements on γ cascades in the decay of ^{75}Se.* Extensive directional correlation measurements were carried out on the two principal γ cascades: 121 keV–280 keV and 136 keV–265 keV. Since the photopeaks were not completely resolved, the number of coincidences counted when the discriminators were set to accept a maximum contribution from one cascade, was corrected for coincidences from the other cascade.

The fluctuations in the relative contributions of the two cascades were kept between narrow limits by electronic gain stabilisation [9].

The main part of the directional correlation equipment was essentially the same as described previously [7] [8]. The coincidence resolving time was 0.3 μsec. Coincidence and single channel counts were taken with the scintillation counters in positions at 15-degree intervals from 90 to 270 degrees. Random coincidences were calculated and subtracted and a solid-angle correction was applied. From a least-squares calculation [14] taking into account $\cos^2\theta$- and $\cos^4\theta$-terms, the following directional correlations are obtained:

121 keV — 280 keV: $W(\theta) = 1 - (0.535 \pm 0.08) \cos^2\theta - (0.035 \pm 0.08) \cos^4\theta$,
136 keV — 265 keV: $W(\theta) = 1 + (0.04 \pm 0.05) \cos^2\theta - (0.06 \pm 0.05) \cos^4\theta$.

If only $\cos^2\theta$-terms are taken into account one obtains:

121 keV — 280 keV: $W(\theta) = 1 - (0.566 \pm 0.02) \cos^2\theta$,
136 keV — 265 keV: $W(\theta) = 1 - (0.017 \pm 0.014) \cos^2\theta$.

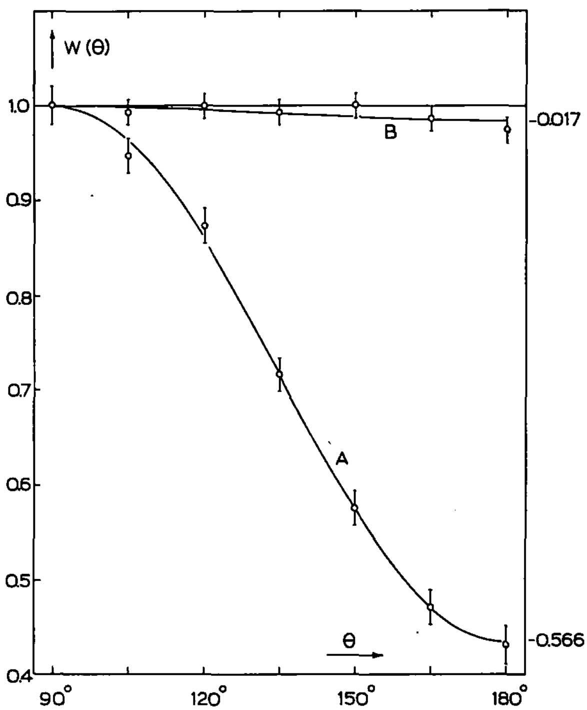

Fig. 4. Directional correlation of the 121 keV — 280 keV (A) and 136 keV — 265 keV (B) cascades. The drawn lines represent the respective least-square curves of $1 + A \cos^2 \theta$; the value of A being indicated in the margin.

In addition, an investigation was carried out to determine the directional anisotropies of the three cascades 66 keV–136 keV, 66 keV–199 keV and 136 keV–199 keV. This measurement is complicated by the large percentages of the stronger cascades detected when a pair of channels is set to accept one of the weaker cascades. Thence the method indicated in the Appendix had to be adopted to analyse the coincidence counting rate obtained in the 90° and 180° counter positions. The results are given in Table IV.

TABLE IV

Directional correlation of the less intensive cascades in the ^{75}Se decay

Cascade *)	Coincidence rate		Anisotropy $\frac{I_{90^\circ} - I_{180^\circ}}{I_{90^\circ}}$
	in 90° position	in 180° position	
66 keV — 136 keV	71 ± 18	92 ± 18	+0.30 ± 0.36
66 keV — 199 keV	50 ± 2	51 ± 2	+0.02 ± 0.05
136 keV — 199 keV	125 ± 17	125 ± 17	0.0 ± 0.19

*) The 121 keV — 199 keV cascade apparently does not contribute coincidences according to Table III.

§ 6. *Polarization- correlation measurements.* Evidence given in § 7 suggests that the 401 keV level and the 304 keV level in ^{75}As have even parity while all other levels have odd parity. In order to obtain more information polarization- correlation measurements were performed on the 121 keV-280 keV and the 136 keV-265 keV cascades. The arrangement is shown in Fig. 5. An anthracene crystal of 30 mm diameter and 20 mm height, fixed to an E.M.I. 6260 photomultiplier, was used as a Compton scatterer, while scintillation

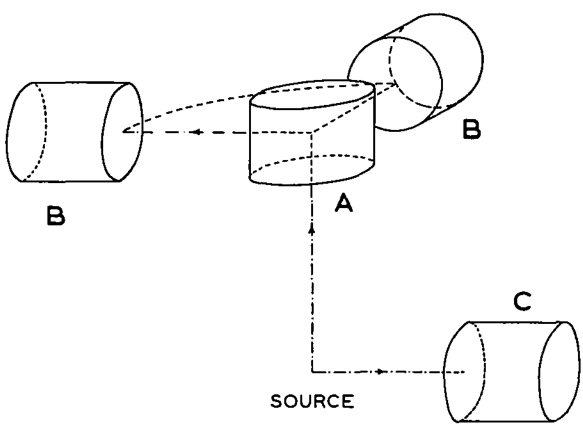

Fig. 5. Schematic drawing of the arrangement for the measurement of polarization - correlation of γ rays.

spectrometers carrying 1" × 1" cylindrical sodium iodide crystals were used for the detection and selection of the scattered and the direct gamma radiation. The sodium iodide crystals were shielded by lead cylinders of 15 mm wall thickness. Additional 15 mm lead shields were placed between these crystals and the source. This source, placed in a fixed position 53 mm below the anthracene crystal, was contained in a 4 mm wide glass tube and consisted of about 0.2 ml of dilute selenic acid with a ^{75}Se content of about 6 micro Curies.

Pulses originating from the three scintillation counters were fed to a triple coincidence arrangement of 0.3 μsec resolving time. Random coincidences amounted to less than 0.1 per hour.

The geometry is such, that the scattering angle of the radiation, detected by the crystal (B) and consequently also its energy, varies widely. The cascade selection was therefore performed by the spectrometer (C), which was set to accept mainly the 280 keV or the 265 keV photopeak, thereby selecting the coincident pulses in (B) caused by scattered photons of 121 or 136 keV energy, respectively. The relative contributions of the 280 keV and 265 keV transitions to the single channel counting rate in (C) were determined from the single channel spectrum in the way described in section 2.

From the result the corresponding relative contributions of the 121 keV-280 keV and 136 keV-265 keV cascades to the triple coincidence counting rate were calculated.

The triple coincidences were detected with the scintilation counter (B) in two different positions. The results of the measurement are given in the fourth column of Table V, where $I_{\parallel}/I_{\perp}$ indicates the coincidence counting rate with counter (B) positioned in the plane of the other two, divided by that rate taken with counter (B) in a position perpendicular to this plane.

TABLE V

Ratio of the scattered radiation counting rate in "parallel" and "perpendicular" directions (for definition see text)

Percentage of coincidences caused by		Polarization measured of	$I_{\parallel}/I_{\perp}$
121 keV — 280 keV cascade	136 keV — 265 keV cascade		
37 ± 6	63 ± 7	121 keV	0.78 ± 0.02
6.6 ± 1.7	93 ± 10	136 keV	0.99 ± 0.05
4.6 ± 2	95 ± 4.5	265 keV	0.98 ± 0.05
53 ± 2.5	47 ± 2	280 keV	0.99 ± 0.05

TABLE VI

Application of corrections to the polarization measurement results

Energy of scattered γ	$I_{\parallel}/I_{\perp}$ for single cascade	Scattering anisotropy A			Polarization anisotropy P
		incorrected $\frac{I_{\parallel}-I_{\perp}}{I_{\parallel}+I_{\perp}}$	corrected for double scattering	corrected for solid angle	
121 keV	0.342 ± 0.077	−0.49 ± 0.06	−0.61 ± 0.075	−0.64 ± 0.08	−0.67 ± 0.10
136 keV	1.035 ± 0.12	+0.03 ± 0.12	+0.04 ± 0.15	+0.04 ± 0.16	+0.04 ± 0.20
165 keV	0.98 ± 0.07	−0.01 ± 0.03	−0.01 ± 0.04	−0.01 ± 0.04	−0.01 ± 0.06
280 keV	1.00 ± 0.13	0.00 ± 0.07	0.00 ± 0.08	0.00 ± 0.08	0.00 ± 0.10

By using the percentages given in the first two columns of Table V the values of $I_{\parallel}/I_{\perp}$ which the cascades would show if completely resolved from each other, can be calculated. They are given in the second column of Table VI.

In the third column of this table the corresponding value of the scattering anisotropy A is given, where:

$$A = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}}.$$

The other columns indicate the gradual change of A if corrections are applied for: *a.* double Compton scattering, which for the lower energy γ rays amounts to 20% of the scattered radiation (column 4), *b.* finite solid angle (column 5). By using the Klein-Nishina formula one finally obtains from column 5 the polarization anisotropy P, which is given in column 6.

The quantity P is defined as follows. We suppose that coincidences are measured between γ_1 and γ_2, emitted in directions perpendicular to each other ($\theta = \pi/2$). Both γ_1 and γ_2 are in general partially polarized. the component of, say, γ_1 polarized in a direction making an angle φ with the normal to the plane through the directions of γ_1 and γ_2 is given by:

$$W(\varphi)\,\mathrm{d}\varphi = (1 + P \cos 2\varphi)\,\mathrm{d}\varphi.$$

The results of the directional and polarization correlation measurements are then found to confirm with the following set of equations:

$$121\text{ keV–}280\text{ keV: } W(\theta, \varphi) = 1 - (0.566 \pm 0.020) \cos^2\theta - -(0.67 \pm 0.10) \sin^2\theta \cos 2\varphi.$$

$$280\text{ keV–}121\text{ keV: } W(\theta, \varphi) = 1 - (0.566 \pm 0.020) \cos^2\theta - -(0.00 \pm 0.10) \sin^2\theta \cos 2\varphi.$$

$$136\text{ keV–}265\text{ keV: } W(\theta, \varphi) = 1 - (0.017 \pm 0.014) \cos^2\theta + (0.04 \pm 0.20) \sin^2\theta \cos 2\varphi.$$

$$265\text{ keV–}136\text{ keV: } W(\theta, \varphi) = 1 - (0.017 \pm 0.014) \cos^2\theta - -(0.01 \pm 0.06) \sin^2\theta \cos 2\varphi.$$

These expressions represent the polarization-correlation relations, if the polarization is measured of the first-mentioned transition.

§ 7. *Discussion.* Before discussing spin and parity assignments to the levels of ^{75}As, it is useful to record the available information:

a. The transition intensities taken from the scintillation spectra of ^{75}Ge and ^{75}Se by Schardt and Welker[5]) and from the present investigation.

b. The decay energy of ^{75}Ge, measured by Schardt and Welker[5]) and of ^{75}Se, calculated from the Q-value of the ^{75}As (p, n) ^{75}Se reaction[10]).

c. The coincidence- and directional correlation measurements performed by Schardt and Welker[5]), Kelly and Wiedenbeck[6]) and in the present investigation.

d. The polarization correlation results of § 6.

e. The 304 keV level half-life measured by Vegors and Axel[11]), by Schardt[12]) and by Campbell and Stelson[13]).

f. The Coulomb excitation γ spectrum obtained by Temmer and Heydenburg[15]).

g. The value of 5/2 measured for the ^{75}Se ground state spin by Aamodt and Fletcher[16]) and that of 3/2 for the ^{75}As ground state spin measured by Jeffries *et al*[17]).

The coincidence measurements all confirm the level scheme given in Fig. 6.

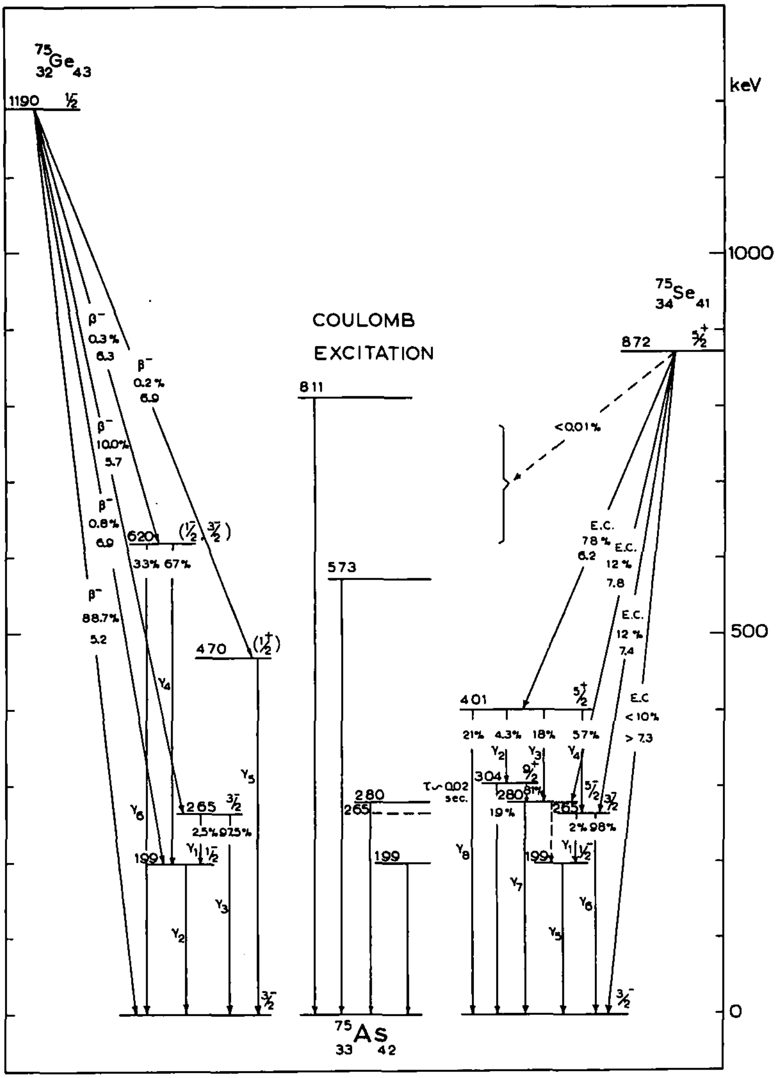

Fig. 6. Excited levels of the ^{75}As nucleus. The three schemes contain the levels excited:

a. in the β^--decay of ^{75}Ge, on the left;

b. by Coulomb-excitation, in the centre;

c. in the electron capture in ^{75}Se, on the right.

The results of the γ intensity measurements given in Tables I and II differ slightly from those by Schardt and Welker[5]. The present results make it more likely that the 280 keV and 265 keV levels in ^{75}As are also fed in the ^{75}Se decay which had been proposed already by Kelly and Wiedenbeck[6]. The calculated percentages of the β^- and electron capture transitions and the resulting log *ft*-values are indicated in Fig. 6.

An isomeric state of 49 seconds half-life has been found in ^{75}Ge[4] [18] [19], and according tot Goldhaber's classification[20], it decays by an E3 transition to the ground state. The half-life fits in smoothly with the half-lives of the selenium isomeric transitions all of which proceed between $(g_{9/2})^3{}_{7/2}$ and $p_{1/2}$ states, which is in agreement with the shell model. As the ground state transition between ^{75}Ge and ^{75}As ($J = 3/2$)[17] is allowed, the ^{75}As ground state must necessarily have negative parity and most likely a $(f_{5/2})^2(p_{3/2})^{-1}$ character, which is quite probable from shell model considerations. Of the other β^--transitions from ^{75}Ge the 925 keV is also allowed, which means that for the 265 keV level in ^{75}As only $1/2^-$ and $3/2^-$ can be considered. The existence of an isomer of 0.02 second half life[11] [12] [13] at 304 keV in ^{75}As is rather surprising but may still find an explanation in accordance with shell theory. The level decays for 81% by emission of conversion electrons to the 280 keV level and for 19% by γ radiation to the ground state of ^{75}As[12]. According to Goldhaber's classification[20] this indicates most probably M2 for the 24 keV and E3 for the 304 keV transition. The spin of the isomeric level is thereby indicated as 9/2 with even parity. Such a level has also been found in ^{73}As by Hayward and Hoppes[21] and there are indications of a similar isomer in ^{77}As[19]. One must conclude that probably in proton shells the $g_{9/2}$ shell starts to fill much earlier than expected so that low $g_{9/2}$ levels are found even at 33 protons. By this assignment the spin of the 280 keV level is fixed at 5/2 with odd parity. The parity assignment is confirmed by the appearance of a 280 keV transition in the $(\alpha, \alpha'\gamma)$ Coulomb excitation spectrum of ^{75}As[15].

The 401 keV ^{75}As level strongly fed in the ^{75}Se decay deexcites by strong γ transitions to the ground state ($3/2^-$), to the 265 keV level ($1/2^-$ or $3/2^-$) and to the 280 keV level ($5/2^-$), and by a weak transition to the 304 keV level ($9/2^+$). Apparently, such a branching pattern can only be explained by a 5/2 assignment to the 401 keV level and a $3/2^-$ assignment to the 265 keV level. The strong transitions then have E1 (or M1) character, the weak one E2 (or M2) character.

The parity of the 401 keV level is uniquely established as even by the present directional and polarization correlation measurements on the 121 keV–280 keV cascade. If the parity were odd this cascade would be characterized as $5/2^- \xrightarrow{\text{M1 + E2}} 5/2^- \xrightarrow{\text{M1 + E2}} 3/2^-$ with possible multipolarity mixing for both γ rays. The mixing parameters δ_1 and δ_2 would have to be chosen such that they yield values for the $\cos^2 \theta$ and $\cos^4 \theta$ coefficients in the directional correlation, and for the polarization of the 121 and 280 keV γ rays in agreement with the experimental results. The appropriate formulae for such a mixed-mixed cascade have been given by Biedenharn and Rose [22]) and Rose [23]) while the necessary coefficients are best taken from the table by Ferentz and Rosenzweig [23]). From such an analysis it can be shown that no set of values for δ_1 and δ_2 under the specified spin and parity conditions exists fitting the experimental data.

Even parity of the 401 keV level implies $5/2^+ \xrightarrow{\text{E1}} 5/2^- \xrightarrow{\text{M1 + E2}} 3/2^-$ character for the 121 keV-280 keV cascade with multipolarity mixing only for the second γ transition. The observed directional anisotropy can be used to determine the E2/M1 amplitude mixing parameter as $\delta_2 = -0.75 \pm$ $\pm$ 0.10. The two roots usually obtained coincide in this particular case. With this value of δ_2 the predicted polarization correlation (polarization of 121 keV transition measured) becomes:

$$W(\theta, \varphi) = 1 - 0.566 \cos^2 \theta - 0.566 \sin^2 \theta \cos 2\varphi.$$

If the polarization of the 280 keV transition is measured one predicts:

$$W(\theta, \varphi) = 1 - 0.566 \cos^2 \theta - 0.068 \sin^2 \theta \cos 2\varphi.$$

Both results agree within the experimental error with the observed polarizations: $P = -0.67 \pm 0.10$, and $P = 0.00 \pm 0.10$ respectively (see § 6).

The high E2/M1 mixing ratio found for the 280 keV transition can be explained by assuming that the 280 keV level ($5/2^-$) and the ground state ($3/2^-$) belong to the same rotational band. This agrees well with the observed Coulomb excitation [15]) of the 280 keV level. Another explanation would be to assign $f_{5/2}$ character to the 280 keV level. The M1 component in the $f_{5/2} \rightarrow p_{3/2}$ ground-state transition would then be forbidden.

The measurements on the 136 keV–265 keV cascade do not provide much new information on the ^{75}As level scheme. All relevant spins and parities are known from the foregoing discussion. The cascade is characterized as $5/2^+ \xrightarrow{\text{E1}} 3/2^- \xrightarrow{\text{M1 + E2}} 3/2^-$ with multipolarity mixing for the second transition only. The mixing parameter δ_2 can be determined from the observed directional anisotropy as $\delta_2 = -0.18 \pm 0.06$ or $\delta_2 = 13 \pm 5$. For both δ_2 values the predicted polarization of both γ_1 and γ_2 is quite small, in accordance with experiment.

The results of the directional correlation measurement of the three weaker cascades in the decay of ^{75}Se (see Table IV), though of low precision, confirm the assignment of spin $\frac{1}{2}$ to the 199 keV level. The low anisotropy of the 66 keV–199 keV cascade in particular points in that direction.

Spins and parities have now been assigned to the ^{75}As levels found from the decays of ^{75}Se and ^{75}Ge. They are indicated in Fig. 6. The log ft values of the β-decay and of the electron capture branches are also shown in the figure. They have been calculated from the relative γ intensities found in sections 2 and 3 by using the information listed in the beginning of this section.

At least three electron capture transitions may be distinguished in the decay of ^{75}Se. The ground state spin of this nuclide was found to be 5/2 [16]. The E.C. transition to the 401 keV level in ^{75}As may then be allowed or first forbidden with $\Delta J = 0$. The log ft value of 6.2 does not decide between these possibilities. The log ft values of 7.5 and 7.4 for E.C. transitions to the $5/2^-$ and $3/2^-$ levels at 280 keV and 265 keV respectively seem to be compatible with even ^{75}Se ground state parity, which classifies these E.C. transitions as first forbidden.

The relative intensity of the electron capture branch leading to the ground state was estimated by Schardt and Welker [5]) to be smaller than 20% which indicates a lower limit of 7.3 for the log ft value of the transition, making it also first forbidden with $\Delta J = 1$. In consequence the parity of the ^{75}Se ground state must be even. The presence of a $5/2^+$ level at 13 keV over a ground state of $9/2^+$ in ^{73}Ge [25]), a nuclide with the same neutron number as ^{75}Se, may indicate that these two states have changed places in ^{75}Se.

A number of levels with energies higher than 401 keV have been indicated in the level scheme. Two of them, at 470 keV and at 620 keV, are fed by β^- branches from ^{75}Ge, with log ft values of 6.9 and 6.3 respectively. An upper level of 0.01% (see Table I) can be set on any transition to ground proceeding from levels higher than 401 keV in the decay of ^{75}Se. Therefore the most likely assignments are $1/2^+$ or $1/2^-$. The 620 keV level decays preferentially to the 199 keV level. This might suggest that it is a rotationally excited level of the latter, in which case the spin would be 3/2 with odd parity. The ^{75}As levels at 573 keV and 811 keV have been attained by Coulomb excitation only. Their parity must therefore be odd. However, no definite conclusion as to the spin of these levels can be made.

Acknowledgement. This investigation is part of the research program of the "Stichting voor Fundamenteel Onderzoek der Materie (F.O.M.)", which was made possible by the "Stichting voor Zuiver Wetenschappelijk Onderzoek (Z.W.O.)". One of the authors had many stimulating discussions with Prof. A. H. Wapstra and Dr. R. van Lieshout, and received many helpful informations from them. He also expresses his thanks to them and to the director of the "Instituut voor Kernfysisch Onderzoek" at Amsterdam for providing the upportunity of performing the measurements on ^{75}Ge at that institute. The authors thank Dr. L. H. Th. Rietjens for his active part in the early stages of this investigation and Dr. C. M. Braams for the correction of the manuscript. The radiochemical department of the "Instituut voor Kernfysisch Onderzoek" has been most obliging in carrying out the chemical separations necessary to purify the ^{75}Ge and the ^{75}Se. The authors are specially indebted to Professor A. H. W. Aten Jr. and Miss G. D. de Feyffer. They also extend their thanks to the operating crew of the Philips cyclotron at Amsterdam.

Appendix

Determination of relative gamma cascade intensities. If two discriminator channels are set in coincidence where one is exclusively counting the pulses of the photopeak due to the transition γ_i while the other is only counting the pulses of the photopeak due to γ_j, the total coincidence rate will be:

$$C_{ij} = K_{ij}\, N_0(1 - \alpha_i)(1 - \alpha_j)\, \varepsilon_{1i}\, \varepsilon_{2j}\, (\Omega_1\Omega_2/16\pi^2) W_{ij}(\theta) \qquad (1)$$

where

N_0	is the desintegration rate of the radioactive source,
K_{ij}	is the part of N_0 which decays through the $\gamma_i - \gamma_j$ cascade,
α_i	is the total conversion coefficient of the transition γ_i,
ε_{1i}	is the photopeak efficiency for quanta of the transition γ_i in the crystal feeding channel 1,
Ω_1	is the solid angle subtended by the crystal feeding channel 1,
$W_{ij}(\theta)$	is the directional correlation of the cascade, normalized such that $\int W_{ij}(\theta)\, d\Omega = 1$.

In most cases a scintillation spectrum will be complex and consist of several photopeaks, Compton distributions, and sometimes pair-peaks. The part of such a spectrum, due to transition γ_i contained in channel 1 can be expressed by a factor a_{1i} relative to the photopeak of γ_i. Then the total coincidence counting rate obtained from two arbitrary channels is

$$N_c = \textstyle\sum_{i,j}\, (a_{1i}\, a_{2j} + a_{2i}\, a_{1j}) C_{ij} = \sum_{ij} A_{ij} C_{ij} \qquad (2)$$

This equation may be set up for every possible pair of channel positions. It is, however, practical to limit the number of channel pairs to the number of cascades, thereby taking n equations in n unknowns, the quantities C_{ij} which are related to the relative cascade intensities K_{ij} by equation (1).

The factors A_{ij} are obtained from a careful analysis of the single channel spectrum of the source, taken under the same conditions, in geometry as in pulse amplification, as prevailed in the coincidence measurement. The stabilisation of the total spectrometer gain mentioned in § 5 has been very helpful in this respect. The calibration spectra necessary for the γ intensity analysis are taken under the same geometrical conditions as the other spectra in order to eliminate effects due to scattering. A channel pair should be set in such a way, that one coincident pair of photopeaks is completely accepted. This is necessary to ensure that one coefficient A_{ij} considerably exceeds the others in magnitude. The corrections introduced by the contributions of the other cascades will then be accordingly reduced and the C_{ij} accuracy enhanced. However, the errors introduced by the method of determination of the coefficients A_{ij} in (2) greatly limit the accuracy to be obtained. The errors in a_{1i} amounted to 1% in the photopeak, 15% in the valley between the photo peak and the Compton ridge, 15% near the maximum of the Compton distribution, and 10% along the lower energy part of the spectrum.

From the obtained quantities C_{ij}, the relative cascade intensities given in Table III were calculated using equation (1) but without taking into account the internal conversion coefficients α.

Received 3-10-57

REFERENCES

1) Ter Pogossian, Robinson and Cook, Phys. Rev. **75** (1949) 995.
2) Cork, Rutledge, Stoddard, and Leblanc, Phys. Rev. **79** (1950) 819.
3) Jensen, Laslett, Martin, Hughes, and Pratt, Phys. Rev. **90** (1953) 557.
4) Smith, Caird, and Mitchell, Phys. Rev. **88** (1952) 150.
5) Schardt, A. W., and Welker, J. P., Phys. Rev. **99** (1955) 816; Phys. Rev. **93** (1954) 916A.
6) Kelly, W. H., and Wiedenbeck, M. L., Phys. Rev. **102** (1956) 1130.
7) Rietjens, L. H. Th., and Van den Bold, H. J., Physica **21** (1955) 701.
8) Rietjens, L. H. Th., thesis Utrecht (1956).
9) Van Egmond, A. J. L., to be published.
10) Trail, C. C., andJohnson, C. H., Phys. Rev. **91** (1953) 474 A.
11) Vegors, S. H. and Axel, P., Phys. Rev. **101** (1956) 1067.
12) Schardt, A. W., Bull. Am. Phys. Soc. **1** (1956) 202.
13) Campbell, E. C. and Stelson, P. H., O.R.N.L. 2076 (1956) 32.
14) Rose, M. E., Phys. Rev. **91** (1953) 610.
15) Temmer, G. M. and Heydenburg, N. P., Phys. Rev. **104** (1956), 973.
16) Aamodt, L. C. and Fletcher, P. C., phys. Rev. **98** (1955) 1224.
17) Jeffries, Loeliger and Staub, Phys. Rev. **85** (1952) 478.
18) Flammersfeld, A., Z. Naturf. **7a** (1952) 295.
19) Burson, Jordan and Leblanc, Phys. Rev. **96** (1954) 1555.
20) Goldhaber, M. and Sunyar, A. W., Phys. Rev. **83** (1951) 93.
21) Hayward, R. W. and Hoppes, D. D., Phys. Rev. **101** (1956) 93.
22) Biedenharn, L. C. and Rose, M. E., Rev. mod. Phys. **25** (1933) 729.
23) Rose, M. E., Phys. Rev. **93** (1954) 477.
24) Ferentz, M. and Rosenzweig, N., Table of F coefficients, ZNL–5324.
25) Welker, Schardt, Friedlander, and Howland, Phys. Rev. **92** (1953), 401.