SCINTILLATION SPECTROMETRY STUDY OF THE ^{73}Se ISOMERIC PAIR

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Synopsis

The positon and the gamma ray spectra of the two ^{73}Se isomers have been studied with a scintillation spectrometer. No new gamma rays have been observed in the decay of the (7.1 ± 0.2) hour activity. The (42 ± 3) min activity shows a positon group of (1.72 ± 0.10) MeV and three gamma rays of 88, 251 and 580 keV and possibly one of 1080 keV. The relative position of the two isomers cannot be deduced from the results of these measurements; no isomeric transition has been identified with certainty. If an isomeric transition occurs, it might be associated with the gamma ray of 88 keV which then should be of $M3$ or $E3$ character, but this interpretation is not very attractive in view of shell model predictions for ^{73}Se .

1. *Introduction.* Two periods are assigned to ^{73}Se , one of 7.1 hours and one of 44 minutes ¹⁾. The existence of an isomeric pair can be expected for a nucleus with 39 neutrons, since the shell model predicts a close lying pair of $p_{1/2}$ and $g_{9/2}$ levels in this region. The 7.1 hour period has been studied in detail; the results obtained by Hayward and Hoppes ²⁾ and those reported by Scott ³⁾ have led to the following decay scheme ¹⁾. A strong 1.32 MeV positon branch populates a level at 425 keV in ^{73}As , which level decays (half-life $6\mu\text{s}$, spin $9/2^+$) by a cascade of a 359 and a 66 keV transition to the ^{73}As groundstate (half-life 76 days, spin $3/2^-$). A weak positon branch of 1.68 MeV ($1\frac{1}{2}\%$) leads to the lower level at 66 keV (spin $5/2^-$). These decay characteristics are compatible with a spin assignment of $9/2^+$ to the 7.1 hour ^{73}Se .

The 44 minute ^{73}Se is less well known. A 1.7 ± 0.2 MeV positon branch has been observed ⁴⁾, its energy having been determined by absorption. The assignment to mass 73 is based on the work by Hooge and Aten ⁴⁾, who observed that the relative cross section for production of the two activities by alpha particle bombardment of germanium is approximately

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constant over the energy range $E_\alpha = 33$ to 52 MeV. The 44 min activity is therefore probably associated with the $p_{1/2}$ state of the isomeric pair. In that case the positron branch is expected to lead directly to the ground state of ^{73}As and no strong gamma rays would be associated with this period.

The relative position of the two activities has not been established so far.

In view of the remaining uncertainties on the decay of the ^{73}Se isomeric pair, a scintillation spectrometer study of their radiations was undertaken.

2. Source preparation, measurements. The sources were produced in the synchro-cyclotron by alpha bombardment of germanium dioxide. An alpha particle energy of 25 MeV was chosen in order to prevent the formation of ^{70}Se by an $(\alpha, 4n)$ reaction; this latter nuclide has been reported to decay by positron emission with a 44 min period. The irradiations lasted 10 to 20 minutes if a high relative abundance of the 44 min ^{73}Se activity was desired while longer irradiation times were chosen when the 7.1 hour activity was the main source needed.

The irradiated target was dissolved in sodium hydroxide and selenium, gallium and arsenic carriers were added. The solution was adjusted to 5N with hydrochloric acid and the selenium reduced with hydroxyl amine. The precipitate was filtered off and dissolved in a few drops of nitric acid. After this the selenium was again changed to the chloride by boiling with hydrochloric acid. The same carriers were added and the selenium was again precipitated in the manner as described above; the precipitate was thereafter dried with alcohol and ether. Small amounts of carrier were used for the sources intended for the beta ray studies.

A stilbene crystal (diameter 4 cm, height 1 cm) was used for the measurement of the positron spectra. The gamma ray spectra were measured with a small NaI(Tl) crystal (25 mm diameter, 25 mm high) and with a larger one (62 mm diameter, 62 mm high) of the well type (31 mm deep, 9 mm diameter). Throughout DuMont photomultiplier tubes (types 6292 and 6363) were used.

Both the beta ray and the gamma ray scintillation spectra very clearly showed the two periods, the best values of the half-life being 7.1 ± 0.2 hours and 42 ± 3 minutes. A *Fermi-Kurie* analysis gave a maximum energy of 1.30 ± 0.05 MeV for the longer period and 1.72 ± 0.10 MeV for the shorter period. (The energy calibration of the beta ray spectrometer was based on measurements of the spectra of ^{32}P , ^{198}Au and of the conversion peaks of ^{137}Cs and ^{207}Bi). The weak higher energy branch in the 7.1 hour period escaped detection. Distortion due to scattering becomes important at approximately half the maximum energy, but nevertheless an upper limit of $\approx 1/8$ can be placed on the intensity of additional positron branches in the 42 min activity with energy above ≈ 700 keV. (See fig. 1).

The gamma ray spectra showed prominent peaks at 360 ± 5 and at

65 ± 2 keV both decaying with a 7.1 hour period in addition to the strong annihilation peak which, of course, decayed with a composite half-life. A number of weaker peaks were resolved from the spectrum and their half-lives were determined. Their intensities relative to the annihilation peak were also determined and elementary considerations then allowed the calculation of their intensities relative to the number of positons associated with the individual activities. The various results obtained are collected in table I, while fig. 2 shows parts of the spectra.

Fig. 1. *Fermi-Kurie* analysis of the positron scintillation spectrum of ^{73}Se ; a) 7.1 hour activity, b) 42 min activity. These results were obtained with the same source but at different times and the initial 7.1 hour contribution was subtracted in fig. 1b by extrapolation from fig. 1a.

TABLE I

Energy and relative intensity values for the gamma rays from 7.1 hour and 42 min ^{73}Se .			
^{73}Se produced by $(^{70}\text{Ge} (25 - \text{MeV } \alpha, n) \text{ chem. scin})$			
$T_{\frac{1}{2}} = 7.1 \pm 0.2$ hours		$T_{\frac{1}{2}} = 42 \pm 3$ min	
$E_{\beta^+} = 1.30 \pm 0.05$ MeV		$E_{\beta^+} = 1.72 \pm 0.10$ MeV	
$E_{\gamma}(\text{keV})$	Rel. int.	$E_{\gamma}(\text{keV})$	Rel. int.
$\gamma^{\pm}$	2×100	$\gamma^{\pm}$	2×100
65 ± 2	105 ± 10	88 ± 2	9 ± 3
360 ± 5	160 ± 15	251 ± 4	20 ± 6
		580 ± 7	8 ± 3
		$1080 \pm 10?$	≤ 0.6

TABLE II

Summing peaks from a composite source of ^{73}Se and $^{73}\text{Se}^m$	
$E_{\gamma}(\text{keV})$	Interpretation
427	$360 + 66$ (7.1 hours)
590	$511 + 66$ (7.1 hours)
780	$511 + 250$ (42 min)
860	$511 + 360$ (7.1 hours)
	$580 + 250$ (42 min)
1080	$511 + 580$ (42 min; very weak)

Some information on possible gamma-gamma coincidences was obtained by the summing technique with the source placed on top of the large

crystal. The summing peaks are listed in table II. The origin of the peak at 860 keV was ascertained in the following manner. The half-life of this very weak peak with the source at about 10 cm from the large crystal was about $5\frac{1}{2}$ hours; its relative intensity increased considerably with the source on top of the crystal, while the half-life of the peak, measured through a lead absorber with the source on top of the crystal, was 7.0 hours. This shows that there is some weak residual summing from the 42 min period and that the rest of the intensity of this peak is entirely due to summing from the 7.1 hour period. Therefore it is concluded that no new gamma rays have been found with certainty in the decay of the 7.1 hour period.

Fig. 2a. The full drawn curve shows the total spectrum due to both activities at the start of the measurements, the dotted curve is the pure 7.1 hour part of the spectrum, normalized at the 65 keV peak. The dashed difference curve shows that the 88 keV peak has the shorter half-life.

The 1080 keV photo peak only shows up clearly at small source-detector distances. It is certainly mainly due to summing, but a small amount of a direct gamma ray transition of this energy cannot be completely excluded; the peak decays with the shorter half-life.

3. *Discussion.* The absence of strong gamma rays in the decay of the 42 min activity shows that the positron group leads directly to the ground state of ^{73}As . From this it follows that the 7.1 hour ^{73}Se state lies 20 ± 100 keV above the 42 min level. Even if one would allow an energy difference of about 250 keV, the relationship between energy and half-life shows that the intensity of a possible direct $M4$ transition would be undetectably low. In order to detect a genetic relationship between the two activities a special

search was made for a possible long lived component in the 251 keV gamma ray, but none was found. No growth of the intensity of the 65 and 360 keV peaks could be detected either. However, these measurements do not yield low upper limits on a possible isomeric transition between the two Se activities (about 50% branching would still be possible).

Although one does not expect an $E3$ isomeric transition to take place in a nucleus with 39 neutrons, the possibility that either the 88 or the 251 keV gamma ray corresponds to an $E3$ isomeric transition was considered (the 580 keV gamma ray would yield too small a half-life). An $E3$ transition

Fig. 2b. Higher energy spectrum of ^{73}Se . The full drawn curve shows the total spectrum which has been analysed into its components (dashed curves). The dotted curve then represents the 7.1 h activity, normalized to the analyzed 360 keV peak. The excess at 251, 511 and 580 keV shows up very clearly. The right hand part represents the part of the spectrum above 500 keV, with the tail due to annihilation in flight and the backscattering coincidences shown for comparison (taken from the pulse height distribution of ^{47}V). The peak at 870 keV has been shown to be entirely due to residual summing, the one at 1080 keV may also contain a direct contribution.

of 88 keV has a total conversion coefficient of about 15, while the value is 0.1 for a 251 keV transition. The total transition intensities would thus become about 1.5 and about 0.2 per positon, respectively. The partial half-lives for the gamma transitions calculated in this way were compared

with the theoretical and empirical estimates $5)^6)$. From these considerations it follows that the 88 keV gamma ray is 10^4 times slower than a single particle transition, while this factor is 10^6 for the 251 keV gamma ray. Other multipolarities were also considered, but only an $M3$ assignment to the 88 keV transition was found to fit better (slowing down factor about 100). However, as mentioned above, only an $M4$ isomeric transition is expected in a nucleus with 39 neutrons and therefore it is preferable to interpret all three gamma rays from the 42 min activity as originating between levels in the daughter nucleus ^{73}As .

Fig. 3. Tentative decay schemes of the 42 min and 7.1 hour ^{73}Se isomers.

The relative intensities of these three gamma rays show that they are fed by allowed positron transitions. The 251 keV gamma ray has the highest intensity, but, within the error limits, the total intensity of the 88 keV transition could be the same if a reasonable correction for conversion (dipole or quadrupole transition) is applied. The results of the summing measurements show that the 251 and 580 keV gamma rays are very probably fed by positons and that they may be in cascade. From the summing measurements it is impossible to decide whether the 88 keV transition is also in cascade with the other two. Its position therefore remains undetermined. It does not seem very plausible to place it on top of the 65 keV level, since no cross-over transition was detected. The position of the doubtful 1080 keV gamma ray cannot be fixed either.

The tentative decay scheme shown in fig. 3 is proposed. The 1.72 MeV positron group must be a composite unresolvable with the scintillation spectrometer, the principal branch having an energy of 1.72 MeV. The total

decay energy of the 42 min ^{73}Se may therefore be somewhat higher, bringing the two ^{73}Se levels even closer together.

The level schemes ¹⁾ of ^{75}As and ^{77}As show a number of low lying odd parity levels. It is thus not unexpected to find that some low lying levels in ^{73}As are populated by the decay of the $\frac{1}{2}^-$ level of ^{73}Se . In ^{75}As and in ^{77}As only one $9/2^+$ level and no $7/2^+$ level have been observed below 1 MeV, so it is not astonishing that no further gamma rays have been found in the decay of the $9/2^+$ level of ^{73}Se .

Acknowledgements. The authors would like to thank Prof. Dr. A. H. W. Aten Jr., Prof. Dr. A. H. Wapstra and Prof. Dr. P. M. Endt for their interest in this work. The kind interest of Prof. Dr. G. Cortini is also gratefully acknowledged. Thanks are due to Mrs. A. Funke-Klopper, who performed the various chemical separations and to the personnel of the synchro-cyclotron for the various irradiations. This work forms part of the research program of the "Stichting voor Fundamenteel Onderzoek (F.O.M.)", which is financially supported by the "Nederlandse Organisatie voor Zuiver-Wetenschappelijk Onderzoek (Z.W.O.)".

Received 24-6-60

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