

## LEVEL STRUCTURE OF $^{73}\text{Se}$ FROM THE $^{72}\text{Ge}(\alpha, 3n\gamma)$ REACTION

M. BEHAR †, A. FILEVICH, G. GARCÍA BERMÚDEZ †, A. M. HERNÁNDEZ and  
M. A. J. MARISCOTTI

*Departamento de Física Nuclear, Comisión Nacional de Energía Atómica, Buenos Aires, Argentina*

Received 20 November 1975

(Revised 12 January 1976)

**Abstract:** States of  $^{73}\text{Se}$ , excited through  $^{72}\text{Ge}(\alpha, 3n\gamma)$  at  $E_\alpha = 30$  to 55 MeV, were studied. Excitation function,  $\gamma$ -ray angular distributions and  $\gamma$ - $\gamma$  coincidences were determined. Levels at the following energies in keV (spin-parity) are proposed: 151( $\frac{3}{2}^-$ ), 505( $\frac{5}{2}^-$ ), 804( $\frac{7}{2}^-$ ) and 1178( $\frac{9}{2}^-$ ). These levels, together with the hitherto known  $\frac{1}{2}^-$  state at 25 keV, exhibit a  $K = \frac{1}{2}$  quasi-rotational structure as regards the energy spacings and branching ratios. A similar recent finding in  $^{75}\text{Se}$  suggests that such a structure is not uncommon in this region of the periodic table. In spite of its spin, no decay into the  $\frac{7}{2}^+$  ground state, interpreted by Kuriyama *et al.* as a deformed three dressed quasiparticle state, is observed although such a decay should be favoured in the present reaction.

E NUCLEAR REACTION  $^{72}\text{Ge}(\alpha, 3n\gamma)$ ,  $E = 30$  to 55 MeV; measured  $\sigma(E, E_\gamma, \theta)$ ,  $\gamma\gamma$ -coin.  $^{73}\text{Se}$  deduced levels,  $J, \pi, \lambda$ ,  $\gamma$ -branching. Enriched Ge target. Ge(Li) detector.

### 1. Introduction

Our knowledge of the  $^{73}\text{Se}$  level scheme was until now limited to the study of the decay of  $^{73}\text{Br}$  [ref. <sup>1</sup>]. Very little is known about spins and other properties of the levels populated in this decay. From the decay of  $^{73}\text{Se}$  [ref. <sup>2</sup>], the ground and the first excited states are known to be  $\frac{7}{2}^+$  and  $\frac{1}{2}^-$ .

The appearance of the  $\frac{7}{2}^+$  state as a ground-state level instead of a  $\frac{9}{2}^+$  state, is an indication of an anomalous coupling. This kind of state has been observed not only in  $^{73}\text{Se}$ , but also in several spherical odd-mass nuclei <sup>3</sup>). Kisslinger and Sorensen <sup>4</sup>) have investigated the low lying states of spherical odd-mass nuclei. In their elaborated work, within the scheme of phonon-quasiparticle coupling for nuclei in the region  $N \approx 40$  and  $32 \leq Z \leq 36$ , their theory could not reproduce the systematic behavior of the low lying levels, especially the lowering of the  $\frac{7}{2}^+$  levels. Recently Kuriyama *et al.* <sup>5</sup>) have developed a new theory, using the “dressed” three quasiparticle concept including the ground-state correlation in the framework of the new Tamm-Dancoff approximation, and they were successful in reproducing the experimental trend in the systematics of the excitation energies. In the framework of this theory, when the

† Fellow of the Consejo Nacional de Investigaciones Científicas y Técnicas.

excitation energy of the mode with spin  $j-1$  ( $\frac{7}{2}^+$  in the present case) becomes equal to or smaller than the energy of the one quasiparticle state with spin  $j$  ( $\frac{9}{2}^+$ ), there may occur an instability of spherical shape and the onset of deformation should be expected. Such an effect has been observed in the level scheme of  $^{75}\text{Se}$  [ref. 6)] where a  $\frac{7}{2}^+$  state lies below a  $\frac{9}{2}^+$  state and a rotational band structure, built on the  $1f_{\frac{7}{2}}$  particle state, has been suggested. As the spin of the ground state of  $^{73}\text{Se}$  is also  $\frac{7}{2}^+$ , one might expect that shape instabilities of the type observed in  $^{75}\text{Se}$  also exist in this nucleus.

The  $^{73}\text{Br}$  nucleus decays to  $^{73}\text{Se}$  by allowed or first-forbidden non-unique  $\beta^+$  transitions <sup>1)</sup>. Since the  $^{73}\text{Br}$  ground state is  $\frac{3}{2}^-$ , the levels fed by this decay would have spins  $\leq \frac{5}{2}$ . Hence, the radioactive decay precludes a search for evidence of deformation through the observation of high spin states.

In addition to the general purpose of increasing our knowledge on the level structure of  $^{73}\text{Se}$  by using a hitherto unused reaction, one particular motivation of this work has been to investigate the validity of the theory of Kuriyama *et al.* <sup>5)</sup> on this nucleus. If the existence of the anomalous  $\frac{7}{2}^+$  state indeed implies a deformed structure, this should give rise to a rotational structure and the  $(\alpha, 3n)$  reaction should be an adequate means to explore this possibility.

## 2. Experimental procedure

### 2.1. EXPERIMENTAL SET-UP

A 55 MeV  $\alpha$ -particle beam was obtained from the Buenos Aires Synchrocyclotron. This beam was subsequently degraded so that energies between 30 and 55 MeV were attained.

The target was oxide of  $^{72}\text{Ge}$  enriched to 82%. The germanium oxide powder was uniformly distributed on a "melinex" strip and bound to it with spray laquer. The target area was about  $5\text{ cm}^2$  and the thickness was  $5\text{ mg/cm}^2$ .

The  $\gamma$ -radiation was detected with a coaxial Ge(Li) detector of 7% efficiency and 2.3 keV energy resolution. Occasionally, in order to see the low energy spectrum with better resolution, a small X-ray Ge(Li) detector with 280 eV of resolution for a 5 keV  $\gamma$ -transition was used.

The analysis of the  $\gamma$ -spectra was performed with the aid of the computer program SAMPO <sup>7)</sup>. To determine photo-peak energies and intensities,  $\gamma$ -ray spectra of radioactive sources were taken before and after each in-beam experiment. The nuclei  $^{152}\text{Eu}$  and  $^{133}\text{Ba}$  were used for energy and efficiency calibration of the Ge(Li) detector in the experimental geometry. All the  $\gamma$ -ray energies are estimated to be accurate to about 0.3 keV. The overall error of our efficiency calibration can be estimated as  $\pm 5\%$ .

## 2.2. EXPERIMENTAL RESULTS

The  $^{73}\text{Se}$  isotope was investigated through the  $^{72}\text{Ge}(\alpha, 3n)^{73}\text{Se}$  reaction. The single  $\gamma$ -ray spectrum taken at  $E_\alpha = 45$  MeV is shown in fig. 1. There are several lines

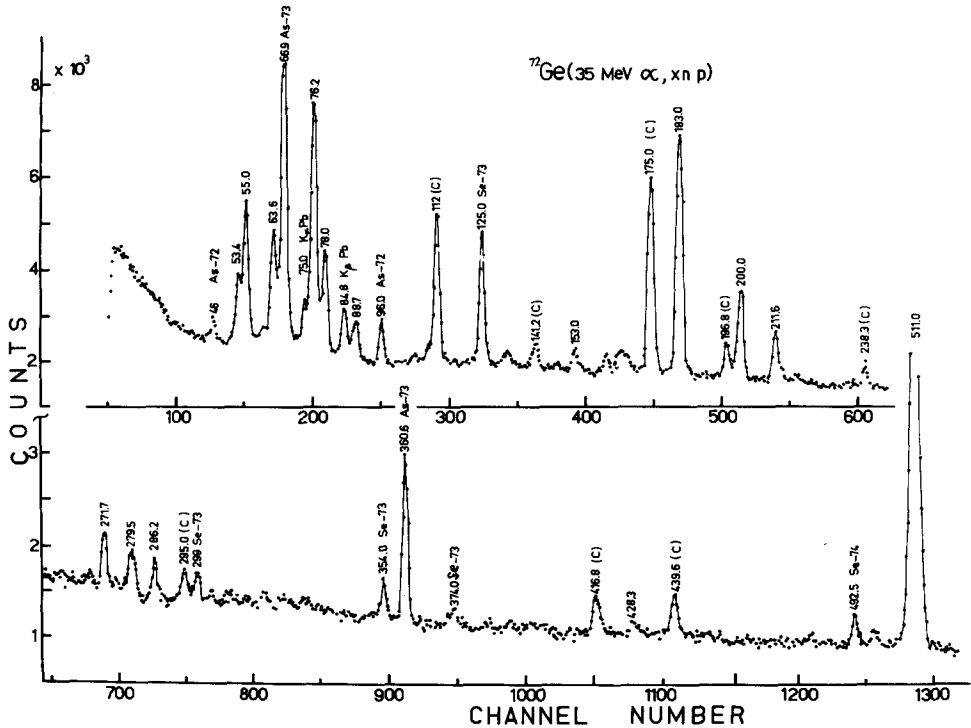


Fig. 1. Low energy part of singles  $\gamma$ -rays spectrum from the  $^{72}\text{Ge}(\alpha, xn)$  reaction at 35 MeV. Lines originating in the target backing are indicated with the letter C.

which belong to other reactions like  $(\alpha, 2n)$ ,  $(\alpha, np)$  and  $(\alpha, 3np)$ . The peaks at 184, 197, 238 and 937 keV originate in the oxygen content of the target. Others are due to reactions in the aluminium target holder.

## 2.3. ISOTOPIC ASSIGNMENT

The isotopic assignment of the  $\gamma$ -rays was done on the following basis:

(a) Relative excitation functions: The  $\alpha$ -beam energy was varied between 30 and 55 MeV in steps of 5 MeV. In fig. 2 the excitation functions for representatives  $\gamma$ -rays from the  $(\alpha, np\gamma)$ ,  $(\alpha, 2n\gamma)$ ,  $(\alpha, 3n\gamma)$  and  $(\alpha, 2np, \gamma)$  reactions are shown. As can be seen, reactions involving two, three and four particles, can be easily distinguished from each other.

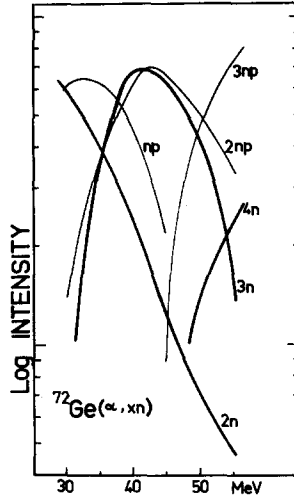


Fig. 2. Excitation functions for the different reactions observed from the bombardment of  $^{72}\text{Ge}$  with  $\alpha$ -particles of energies between 30 and 55 MeV. The curves correspond to the most intense  $\gamma$ -rays in each reaction.

(b) In order to distinguish between the  $(\alpha, 3n\gamma)$  and  $(\alpha, 2np\gamma)$  processes, the following criteria were applied:

(i) A 64.9 and 125.5 keV  $\gamma$ -transition are known from the work of Murray *et al.*<sup>1)</sup> to belong to  $^{73}\text{Se}$ . Similar relative excitation functions and coincidences with the 125.2 keV transition make it possible to assign the other  $\gamma$ -rays to the  $^{73}\text{Se}$  isotope.

(ii) To ensure that the observed 125.2 keV transition belongs to  $^{73}\text{Se}$ , the yield of the 125.2 peak in the on-line spectrum was compared with that of 361 keV transition

TABLE 1  
Summary of the results of the present experiment

Energy <sup>a)</sup> (keV)	Intensity <sup>b)</sup>	Spin sequence $J_i \rightarrow J_f$	$A_2$	$A_4$	$Q = \frac{\delta^2}{1+\delta^2}$	Adopted multipolarity <sup>c)</sup>
65.0	434					
125.2	1605	$\frac{3}{2} \rightarrow \frac{1}{2}$	$-0.40 \pm 0.02$	$-0.02 \pm 0.18^*$	$\leq 0.1\%$ or $75\%$	$M1 \pm \leq 0.1\%$ E2
299.3	485	$\frac{2}{2} \rightarrow \frac{3}{2}$	$-0.12 \pm 0.05$	$0.10 \pm 0.12^*$	$\leq 4\%$	$M1 \pm \leq 4\%$ E2
354.2	1000	$\frac{5}{2} \rightarrow \frac{3}{2}$	$-0.46 \pm 0.05$	$0.10 \pm 0.12^*$	$\leq 1\%$	$M1 \pm \leq 4\%$ E2
373.8	476	$\frac{3}{2} \rightarrow \frac{1}{2}$	$-0.37 \pm 0.14$	$0.24 \pm 0.34^*$	$\leq 2\%$ or $\geq 90\%$	$M1 \pm \leq 2\%$ E2
479.7	333	$\frac{2}{2} \rightarrow \frac{1}{2}$				E2
653.6	620	$\frac{2}{2} \rightarrow \frac{3}{2}$	$0.45 \pm 0.11$	$-0.31 \pm 0.12$		E2
673.4	420	$\frac{2}{2} \rightarrow \frac{2}{2}$	$0.35 \pm 0.12$	$-0.40 \pm 0.16$		E2
912.4	1307	$\frac{2}{2} \rightarrow \frac{2}{2}$				

<sup>a)</sup> Energies are accurate to  $\pm 0.15$  keV.

<sup>b)</sup> Typical intensity error is about 10 %.

<sup>c)</sup> See sect. 4.

corresponding to the decay of  $^{73}\text{Se}$ . The 361 keV line was recorded during a determined time interval after the beam was interrupted and the total integral was obtained by using the well known decay constant of  $^{73}\text{Se}$ . After taking into account the other transitions feeding the ground state (see level scheme in the following), the intensity balance was found satisfactory.

(iii) A slight difference between the  $(\alpha, 3n\gamma)$  and  $(\alpha, 2np\gamma)$  reactions is noticeable at 30 MeV, where the former is negligible.

From the above arguments the lines at 65.0, 125.2, 299.3, 354.2, 373.8, 479.7, 653.6, 673.4 and 912.4 keV were assigned as transitions in  $^{73}\text{Se}$ . The energies and intensities are given in table 1. These  $\gamma$ -rays were fitted into a level scheme on the basis of  $\gamma$ -ray energy combinations,  $\gamma$ -intensity balance,  $\gamma$ - $\gamma$  coincidence relationships and  $\gamma$ -ray angular distribution.

#### 2.4. COINCIDENCE MEASUREMENTS

The coincidence spectrometer consisted of two Ge(Li) detectors of 7% and 6% efficiency, with similar energy resolution (2.3 keV at 1332 keV). A conventional coincidence circuit of  $2\tau = 40$  nsec resolution time, was used in conjunction with a 4096 Intertechnique multichannel analyzer. Gates were set on the 65, 125, 299, 354, 374 and 912.4 keV  $\gamma$ -rays. For the 65 keV line the small X-ray detector was used to provide the gating pulses.

A typical coincidence spectrum with the gate set on the 125 keV line is shown in fig. 3. The results of the coincidence experiments are summarized in table 2.

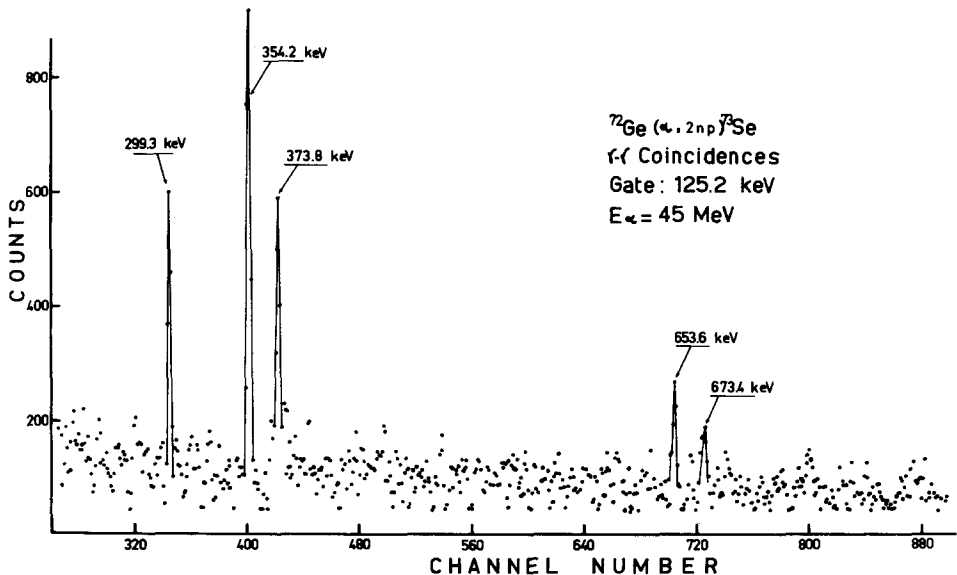


Fig. 3. The  $\gamma$ -ray spectrum in coincidence with the 125 keV transition.

TABLE 2  
The  $\gamma$ - $\gamma$  coincidence intensities from the present experiment <sup>a)</sup>

Gate $E_\gamma$	125.2	299.3	354.2	373.8
125.2				
299.3	457	100	181	92
354.2	954	122		82
373.8	576	130	92	
479.2		W		W
653.6	500			W
673.4	368		W	

<sup>a)</sup> Intensities corrected with the detector efficiency are given in arbitrary units. The letter W denotes weak coincidence.

## 2.5. ANGULAR DISTRIBUTION MEASUREMENTS

To obtain angular distributions;  $\gamma$ -ray spectra were taken at seven angles ( $75^\circ$ ,  $90^\circ$ ,  $100^\circ$ ,  $110^\circ$ ,  $120^\circ$ ,  $130^\circ$  and  $135^\circ$ ) with respect to the beam direction. The target was rolled to a cylindrical shape of 3 mm in diameter and 3 cm in height.

The movable detector was placed 15 cm from the target. To normalize the spectra taken at different angles, the output of a pulser triggered by pulses from a monitor detector was fed into the preamplifier of the moving detector.

The normalized peak areas obtained from these spectra were then fitted to the usual angular correlation function  $W(\theta) = 1 + A_2 P_2(\cos \theta) + A_4 P_4(\cos \theta)$ . The parameters  $A_2$  and  $A_4$  determined in this way are related to the tabulated <sup>8)</sup> coefficients  $A_2^{\max}$  and  $A_4^{\max}$ , which correspond to total alignment, by the attenuation coefficients  $\alpha_K = A_K/A_K^{\max}$ .

The results of our angular distribution measurements are shown in fig. 4. The solid curves represent the fit to the data. The experimental results are shown in

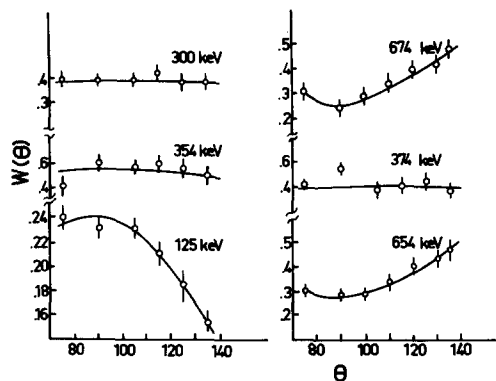


Fig. 4. Angular distribution results for the  $\gamma$ -rays assigned to  $^{73}\text{Se}$ . The solid curves represent the best theoretical fit to the experimental points.

table 1. Whenever  $A_4$  was consistent with zero, a second fit with  $A_2$  as the only free parameter, and  $A_4 \equiv 0$ ; was carried out. These cases are indicated in table 1 with an asterisk under the column headed  $A_4$ .

### 3. Analysis and discussions

#### 3.1. ENERGY LEVELS AND DECAY SCHEME

The energy levels of  $^{73}\text{Se}$  and their decay scheme are shown in fig. 5. The scheme was constructed on the basis of the relative  $\gamma$ -intensities, energy combinations and coincidence experiments.

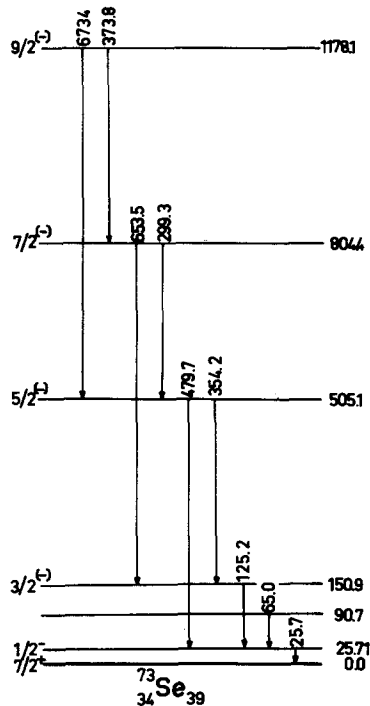


Fig. 5. Level of  $^{73}\text{Se}$  obtained in the present work. The 25.7 keV transition was weakly observed in a measurement carried out with an X-ray detector. Its placement in the scheme is based on the results of ref. <sup>1</sup>).

Comparing our results with those from the decay work <sup>1)</sup> only two levels, the ones at 91 keV and the 151 keV, are common to both studies.

The observation of crossover transitions facilitates the construction of the level scheme. The coincidence results shown in table 2 confirm without ambiguity the placement of all the  $\gamma$ -rays except two:

- (i) The 65.0 keV transition, which defines the 91 keV level is placed in the decay

scheme of  $^{73}\text{Se}$ , due to its excitation function and also because the 65 keV transition is observed in the decay of  $^{73}\text{Br}$  [ref. <sup>1</sup>]. The coincidence experiment has given a negative result.

(ii) The 912 keV line is not in coincidence with any other. It cannot be the same as the 913.6 keV observed by Murray *et al.* <sup>1</sup>) because we do not observe the other lines which deexcite the 940 keV level. The assignment is again based on the excitation function.

### 3.2. SPIN ASSIGNMENTS AND MULTIPOLARITY OF THE $\gamma$ -TRANSITIONS

In the present case the results of the angular distribution measurements allow us to determine without ambiguity the spin of the following levels:

*The 151 keV level.* The angular distribution of the 125 keV transition permits us to assign spin  $J = \frac{3}{2}$  to this level, on the basis that the 25 keV state has  $J = \frac{1}{2}$ . A  $\frac{1}{2}-\frac{1}{2}$  transition would give an isotropic distribution and a  $\frac{5}{2}-\frac{1}{2}$  transition would require a positive  $A_2$  in contradiction with the experimental result.

*The 804 keV level.* This level de-excites to the 505 keV level by a 299 keV transition and to the 151 keV, through the 654 keV  $\gamma$ -ray. The angular distribution of the latter is only compatible with a  $\Delta I = 2$  transition so that spin  $J = \frac{7}{2}$  is assigned to the 804 keV level.

*The 505 keV level.* Since the angular distributions of the 299 and 354 keV  $\gamma$ -rays are both consistent with  $\Delta J = 0, 1$  the only spin compatible with both measurements is  $J = \frac{5}{2}$  for this level.

*The 1178 keV level.* The spin of this level is fixed as  $J = \frac{9}{2}$  since the 673 keV  $\gamma$ -ray feeds the  $J = \frac{5}{2}$ , 505 keV state, and exhibits an angular distribution only consistent with a  $\Delta I = 2$  transition.

The mixing ratios of the  $\gamma$ -rays can be extracted from the corrected  $A_2^{\max}$  and  $A_4^{\max}$  angular distribution coefficients

$$A_2^{\max} = A_2/\alpha_2, \quad A_4^{\max} = A_4/\alpha_4.$$

The  $\alpha_2$  coefficients can be obtained by comparing the tabulated  $A_2^{\max}$  with the experimental  $A_2$  for the  $\frac{7}{2}-\frac{3}{2}$ , 654 keV transition and the  $\frac{9}{2}-\frac{5}{2}$ , 674 keV transition, since these are pure quadrupole transitions.

For the 654 keV transition  $\alpha_2 = 0.88 \pm 0.28$  and for the 675 keV transition  $\alpha_2 = 0.80 \pm 0.25$ . Despite the fact that both coefficients characterize different levels, a weighted average of them can be taken as a typical attenuation coefficient. The result is  $\alpha_2 = 0.85 \pm 0.17$ . The corresponding  $\alpha_4$  can be calculated <sup>8</sup>) and it is  $\alpha_4 = 0.6$ . Assuming that these values also apply to the 505 and 151 keV levels, the corrected  $A_2$  and  $A_4$  values for the different transitions can be computed and given in table 1. From them, the quadrupole content  $Q = \delta^2/(1+\delta^2)$ , also shown in table 1, can be deduced.

### 4. Discussion and conclusions

As pointed out by Kuriyama *et al.* in their work on collective excitation in spherical odd-mass nuclei, the crossing of energy levels between the  $\frac{7}{2}^+$  anomalous coupling state and the  $\frac{9}{2}^+$  single-particle state would indicate the appearance of an instability of the spherical odd-mass nuclei.

In <sup>73</sup>Se, the ground state is  $\frac{7}{2}^+$  and therefore one expects some indication of a nuclear deformation. However, in the present work we have not obtained evidence for a rotational band built on this state as it should be expected if it was deformed. On the other hand, the levels observed here which decay to the  $\frac{1}{2}^-$  state at 25 keV actually exhibit a spin sequence, energy spacings, and decay patterns, all of which suggest a rotational structure.

In order to explore this point further we have adjusted the energy sequence to the expression

$$E_{Ik} = \varepsilon_k + \frac{\hbar^2}{2\mathcal{J}} [I(I+1) - \frac{1}{2} + a(-1)^{I+\frac{1}{2}}(I+\frac{1}{2})],$$

characteristic of a  $K = \frac{1}{2}$  rotational band. The results are summarized in fig. 6. Experimental values are shown in horizontal solid lines, while the calculated energy differences  $E_I - E_{\frac{1}{2}}$  are plotted as a function of the decoupling parameter  $a$  assuming a moment of inertia  $\mathcal{J} = 0.01 \hbar^2$ .

It is difficult to pick out a particular value of the parameter  $a$  for which the fit is distinctly improved; within the range  $-0.2 < a < 0$ , any value of  $a$  essentially yields a similar  $\chi^2$ .

The moment of inertia used in the calculation is rather small; it is about three

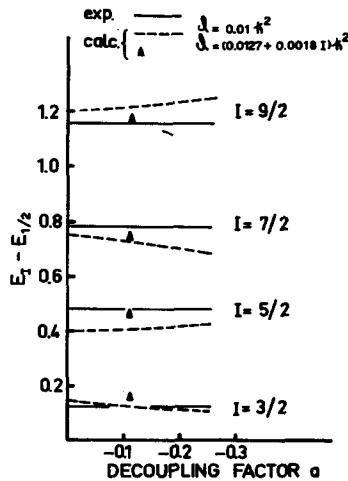


Fig. 6. Comparison of experimental (solid lines) and calculated energies for <sup>73</sup>Se. The dashed lines are obtained with the rigid rotor formula and are shown as a function of the decoupling parameter  $a$ . The triangles represent the best fit when the moment of inertia is allowed to vary linearly with the angular momentum.

times smaller than those typically found in the well deformed rare-earth nuclei, and comparable to those of nuclei with  $N = 88-90$ , that is, just where the transition between spherical and deformed shapes takes place. Thus, taking this into account plus the fact that the formula above corresponds to the strong coupling limit, the overall fit is regarded as fairly good. In fact, because transitional nuclei exhibiting small ground-state moments of inertia are soft (i.e. moment of inertia increases with spin  $I$ ), a least-squares fit was carried out allowing the moment of inertia to vary linearly with  $I$ . The result of this improved fit is indicated in Fig. 6 by solid triangles. The parameters, in this case, are  $a = -0.11$  and  $\mathcal{J} = (0.0127 + 0.0018 I)\hbar^2$ .

It is of interest to note that the level sequence which has been tentatively interpreted as a rotational band in  $^{75}\text{Se}$  [ref. 6)], is approximately reproduced (with the exception of the first excited state) with a similar moment of inertia,  $\mathcal{J}(^{75}\text{Se}) \approx 0.013\hbar^2$ , although in this case its variation with  $I$  seems to be negligible.

If the rotational interpretation is correct, the parity of all the levels must be the same and hence is negative since the ground state of the band is known <sup>2)</sup> to have negative parity.

TABLE 3  
Experimental and predicted branching ratios

Level energy (keV)	$I$	$T(M1 + E2, I \rightarrow I-1)/T(E2, I \rightarrow I-2)$		
		single part.	strong coupl <sup>a)</sup>	exp.
479	$\frac{5}{2}^-$	1000	$> 6$	$3.4 \pm 0.6$
778	$\frac{3}{2}^-$	100	$> 0.06$	$0.78 \pm 0.10$
1153	$\frac{1}{2}^-$	100	$> 0.30$	$1.13 \pm 0.20$

<sup>a)</sup> The strong coupling value depends on the mixing ratio  $\delta^2$ . In those cases (see table 1) where more than one mixing ratio is compatible with the experimental result, only the lower one is consistent with the measured branching ratio.

A second test for the rotational band picture of this level scheme is to compare the experimental branching ratio for each level with the single-particle and unified model predictions (table 3). In those cases where more than one  $Q$ -value was obtained (see table 1) the lower one was used as the other, implying a predominant quadrupole character is not compatible with either model. As can be seen, the results again show support for the rotational band hypothesis.

It is noteworthy that no transitions to the  $\frac{7}{2}^+$  are observed despite the comparable spins involved. At the same time, the 26 keV  $\frac{1}{2}^- \rightarrow \frac{7}{2}^+$  transition is 100 times hindered with respect to the Weisskopf estimate. This forbiddness clearly indicates that the  $\frac{7}{2}^+$  is not a single-particle state in accord with the three "dressed" quasiparticles model in which the  $\frac{7}{2}^+$  state is interpreted as a state with seniority  $r = 3$  while the  $\frac{1}{2}^-$  is probably a state with  $r = 1$ .

In conclusion, the results of the present work can be summarized as follows.

The levels of  $^{73}\text{Se}$  excited in the  $(\alpha, 3n)$  reaction decay almost exclusively into the  $\frac{1}{2}^-$  state at 26 keV, and they follow a pattern which can be tentatively interpreted as a quasirotational  $K = \frac{1}{2}$  band. No such a structure is observed for the  $\frac{7}{2}^+$  ground state which is presumably described by the model of Kuriyama *et al.*<sup>5)</sup> and hence it should be deformed. Since the residual nucleus produced in this reaction should favour the population of high spin states this lack of feeding into the  $\frac{7}{2}^+$  state is somewhat surprising and stimulates further investigation.

Finally, the non-observation of any transition in coincidence with the 65 keV  $\gamma$ -ray is somewhat intriguing. This fact can be understood if the 91 keV state is: (a) only populated by high energy transitions; (b) only populated by (many) weak transitions; (c) has a long half-life ( $\gtrsim 100$  nsec). Unfortunately this last possibility could not be checked owing to the presence of the much more intense 67 keV transition corresponding to the  $^{72}\text{Ge}(\alpha, 2np)^{73}\text{As}$  reaction.

### References

- 1) G. Murray, W. J. K. White, J. C. Willmott and R. F. Entwistle, Nucl. Phys. **A142** (1970) 21
- 2) G. Murray, W. J. K. White, J. C. Willmott and R. F. Entwistle, Phys. Lett. **28B** (1968) 35
- 3) G. Graeffe, Nucl. Phys. **A127** (1969) 35;  
D. J. Horen and W. H. Kelly, Phys. Rev. **145** (1966) 988;  
S. O. Schriber and M. W. Johns, Nucl. Phys. **A196** (1967) 337
- 4) L. S. Kisslinger and R. A. Sorensen, Rev. Mod. Phys. **35** (1963) 853
- 5) A. Kuriyama, T. Marumori and K. Matsuyuanagi, Prog. Theor. Phys. **45** (1971) 784; **47** (1972) 498
- 6) C. Protop, K. O. Zell, H. G. Friedericks, B. Herts and P. O. Brentano, Proc. Int. Conf. on nuclear physics, Munich 1973, ed. J. de Boer and H. J. Mang (North-Holland, Amsterdam, 1973);  
T. Sugimitsu, Nucl. Phys. **A224** (1974) 199
- 7) J. T. Routti and S. G. Prussin, Nucl. Instr. **72** (1969) 125
- 8) E. Der Mateosian and A. W. Sunyar, Nucl. Data Tables **13** (1974) 391