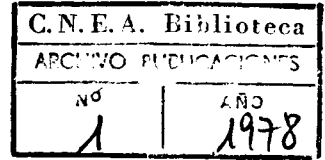


1.E.1:
3.A

Nuclear Physics A309 (1978) 285–300; © North-Holland Publishing Co., Amsterdam
Not to be reproduced by photoprint or microfilm without written permission from the publisher



IN-BEAM STUDY OF ^{70}As

A. FILEVICH, M. BEHAR †, G. GARCÍA BERMÚDEZ †† and M. A. J. MARISCOTTI
Departamento de Física, Comisión Nacional de Energía Atómica, Buenos Aires 1429, Argentina

and

E. DER MATEOSIAN and P. THIEBERGER

Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, USA †††

Received 17 August 1977

(Revised 9 June 1978)

Abstract: Nuclear states of ^{70}As were studied through the $^{69}\text{Ga}(\alpha, 3n)$, $^{60}\text{Ni}(^{12}\text{C}, np)$ and $^{63}\text{Cu}(^{10}\text{B}, 2np)$ reactions at various bombarding energies between 30 and 55 MeV. Excitation functions, γ -ray angular distributions, γ - γ coincidences, and γ -time distributions with respect to the beam bursts, were determined. Levels at 32.0, 167.0, 390.4, 485.4, 566.7, 869.1, 887.9, 898.7, 933.4, 1045.7, 1675.9, 1752.0, 1809.2, and, tentatively at 2030 keV, were observed. All levels below 900 keV can be identified with levels seen with the $(p, n\gamma)$ reaction. Tentative spin assignments extend up to $J = 9$. Two previously reported isomers are confirmed. The present measurements yield 3.3 ± 0.7 and 4.4 ± 0.1 ns for the 485.4 and 887.9 keV states, respectively. No collective features, as in the lighter isotope ^{68}Ga , were found. The levels below 1 MeV are likely to be described by simple shell-model configurations. The spacing of the proposed $J = (4), (5),$ and (6) levels is analogous to that in ^{72}As and ^{74}As . The behavior of their excitation energy as a function of N suggests the configurations $\{\pi p_{3/2}^{-1}, \nu g_{9/2}\}$ or $\{\pi f_{5/2}, \nu g_{9/2}\}$ for these states.

E NUCLEAR REACTIONS $^{69}\text{Ga}(\alpha, 3n\gamma)$, $^{60}\text{Ni}(^{12}\text{C}, np)$, $^{63}\text{Cu}(^{10}\text{B}, 2np)$, $E = 30\text{--}55$ MeV; measured $\sigma(E, E_\gamma, \theta, t)$, $E_\gamma, I_\gamma, \gamma\gamma$ -coin. ^{70}As deduced levels, $J, T_{1/2}$. Enriched ^{69}Ga , ^{60}Ni and ^{63}Cu targets.

1. Introduction

The present work was undertaken with the purpose of studying high-spin states in ^{70}As and represents an extension of previous work ^{1,2}) on ^{72}As and ^{74}As carried out with a similar aim. The latter nuclei share some common features such as the 2^- ground-state configuration and a certain regularity in the energy spacings of $J = 4, 5$ and 6 levels. In the case of ^{72}As , for which a larger body of data is available ³), it is possible to identify the first-excited levels with simple shell-model configurations ^{1,4}).

† Present address: Institut für Kernphysik, Kernforschungsanlage Jülich, Jülich, West Germany.

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

††† This work has been supported by CONICET, Argentina, and the National Science Foundation and DOE of the USA, Contract INT76-04613.

The negative parity of their 2^- ground states and other low-lying states reflects the influence of the neutron $g_{\frac{7}{2}}$ orbit in the structure of these nuclei.

Differences with ^{70}As are expected because the neutron $f_{\frac{7}{2}}$ shell is not filled as it is in the heavier isotopes. Thus the $\{f_{\frac{7}{2}}, \nu f_{\frac{7}{2}}^{-1}\}$ configuration is expected to play a dominant role in the structure of the low-lying levels. This is confirmed by the spin-parity properties of the low-lying levels of neighboring odd- A nuclei and by the measured $^5) J^\pi = 4^+$ for the ^{70}As ground state.

Hence by studying the similarities and differences between ^{70}As and the two heavier isotopes one may hope to learn more about their intrinsic structure. Also, the recent observation $^{6,7)}$ of quasi-rotational bands in doubly odd nuclei lying in the vicinity of the As isotopes, in particular ^{68}Ga which has the same neutron number as ^{70}As , adds interest to the study of ^{70}As as its structure could be expected to show transitional properties.

No information on excited states with spins larger than 2 was hitherto available. The decay of ^{70}Se has been studied by Ten Brink *et al.* $^8)$. Nine levels are reported below 600 keV with spin assignments which vary between 0 and 2. These authors find that these states can be explained in terms of the $f_{\frac{7}{2}}$, $p_{\frac{3}{2}}$ and $p_{\frac{1}{2}}$ shell-model orbits. Furthermore, from their results and previous data $^9)$, it is concluded that the 2^- state, analogous to the ground states of ^{72}As and ^{74}As , should lie above ≈ 400 keV.

Recently Ten Brink *et al.* $^{10)}$ have reported on states of ^{70}As observed with the $^{70}\text{Ge}(p, n\gamma)$ reaction. A measurement of the half-life of the first-excited 2^+ state at 32.0 keV supports the idea that both this state and the ground state stem predominantly from the $\{\pi f_{\frac{7}{2}}, \nu f_{\frac{7}{2}}^{-1}\}_J$ multiplet. They also observed a strong 81.1-318.5-134.5 keV γ -cascade which they suggest may involve higher-spin states with the $\{\pi f_{\frac{7}{2}}, \nu g_{\frac{7}{2}}\}$ configuration. In a preliminary report of the results obtained with the $^{69}\text{Ga}(\alpha, 3n)$ and $^{70}\text{Ge}(\alpha, 3np)$ reactions $^{11)}$ this cascade was also observed but fitted incorrectly into a level scheme. In the present work, several reactions involving α , ^{12}C , and ^{10}B projectiles have been used in order to reach high-spin states in ^{70}As . The details of the experiments and a discussion of the results are given in the following sections.

2. Experimental procedures

Several reactions leading to ^{70}As were used in the present study. The $^{69}\text{Ga}(\alpha, 3n)$ reaction was studied between 30 and 55 MeV and preliminary runs were also performed with the $^{70}\text{Ge}(\alpha, 3np)$ reaction, by means of the α -particle beam from the Buenos Aires Synchrocyclotron. In both cases about 10 mg of enriched targets (99.7% and 70%, respectively) were used in the form of oxides deposited on $4 \mu\text{m}$ mylar backings spread over $\approx 1 \text{ cm}^2$ area.

The $^{60}\text{Ni}(^{12}\text{C}, np)$ reaction at 50 MeV and the $^{63}\text{Cu}(^{10}\text{B}, 2np)$ reaction at 40 MeV were utilized at the Brookhaven National Laboratory MP7 tandem. These measurements were carried out with thick targets ($> 5 \text{ mg/cm}^2$) and the bombarding ener-

gies were chosen after comparison of γ -spectra accumulated at energies between 35 and 55 MeV.

All measurements were performed with various Ge(Li) counters which are indicated in each case below. Conventional electronics and data analysis procedures were used. Energy and efficiency calibrations were achieved by using sources of ^{133}Ba , ^{60}Co , ^{137}Cs , ^{241}Am , ^{152}Eu and ^{22}Na .

2.1. ISOTOPIC ASSIGNMENT AND SINGLES MEASUREMENTS

Excitation functions corresponding to reactions involving two, three and four outgoing particles can be easily distinguished from each other.

The excitation functions of some γ -rays assigned to the $^{69}\text{Ga}(\alpha, 3n)^{70}\text{As}$ reaction for energies between 30 and 55 MeV are shown in fig. 1. The competing $^{69}\text{Ga}(\alpha, 2np)$ reaction which may have rather similar excitation function to the $(\alpha, 3n)$ reaction, may nevertheless be identified since the strongest γ -ray transitions in the resulting ^{70}Ge nucleus are well known.

The lines assigned to ^{70}As , which were observed with both $^{69}\text{Ga}(\alpha, 3n)$ and $^{70}\text{Ge}(\alpha, 3np)$ reactions, show excitation functions fully consistent with the respective reactions. Most of these assignments have been more recently confirmed by a study of ^{70}As with the $(p, n\gamma)$ reaction ¹⁰.

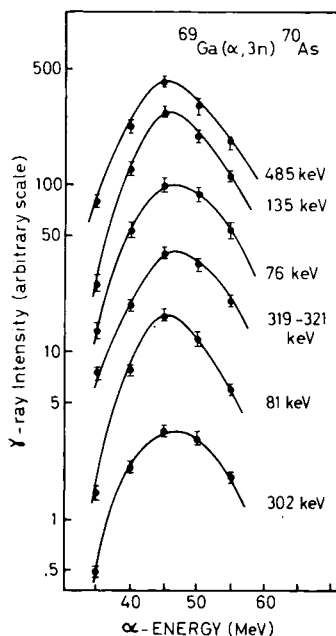


Fig. 1. Excitation functions for different γ -rays assigned to the ^{70}As nucleus, observed during the bombardment of ^{69}Ga with α -particles of energies between 35 and 55 MeV.

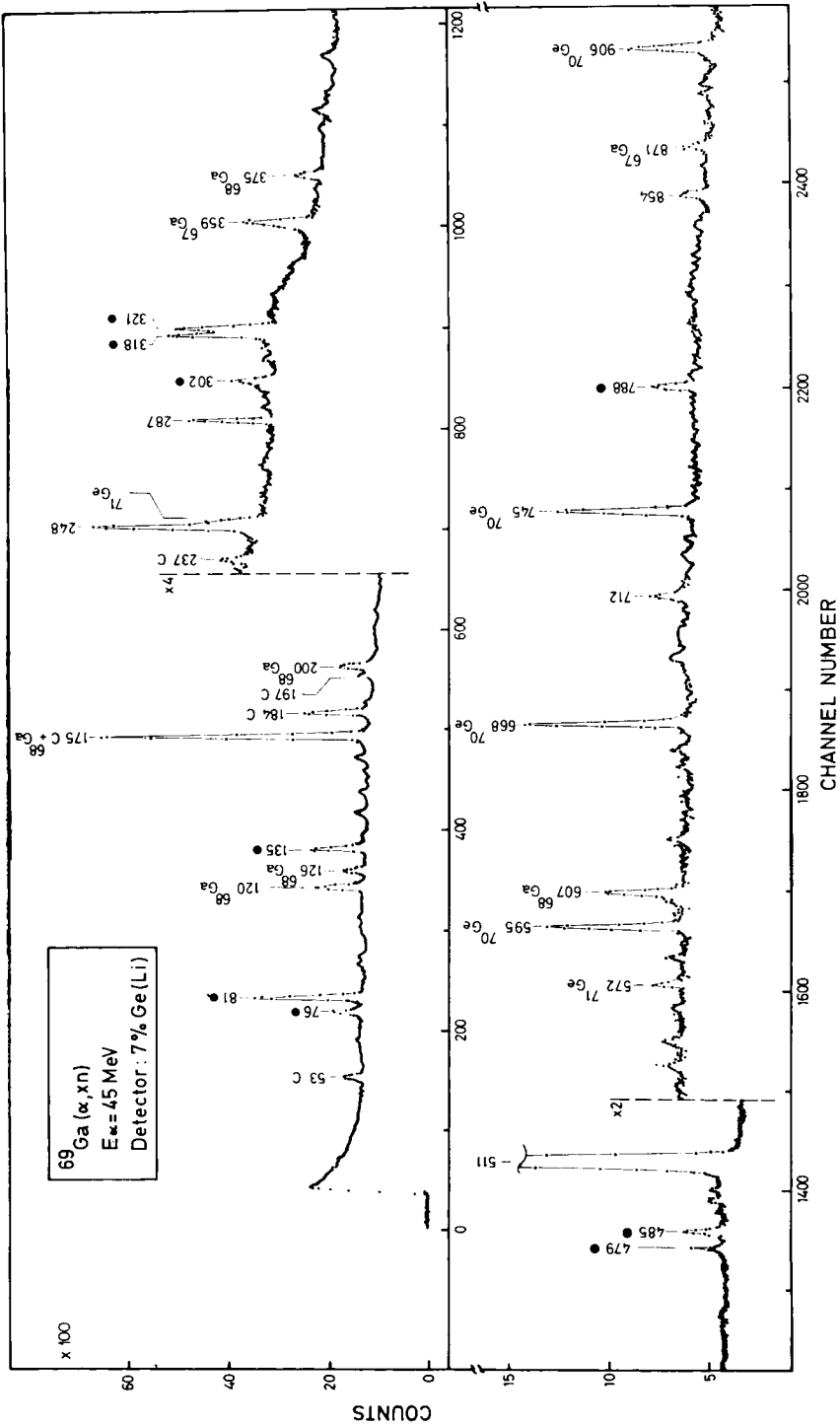


Fig. 2. Singles γ -ray spectrum from the bombardment of ^{69}Ga at $E_\alpha = 45 \text{ MeV}$. The γ -rays assigned to ^{70}As are labeled with solid dots and the lines originating in the target backing with the letter C.

The energies and intensities of the γ -rays of ^{70}As observed in this work are given in the first three columns of table 1. Columns 2 and 3 list the intensities obtained with the $^{69}\text{Ga}(\alpha, 3n)$ and $^{60}\text{Ni}(^{12}\text{C}, np)$ reactions, respectively.

TABLE 1
Energies, intensities and angular distribution coefficients for ^{70}As γ -rays

E_γ (± 0.2) (keV)	I_γ		A_2/A_0	A_4/A_0
	from $^{69}\text{Ga}(\alpha, 3n)$	from $^{60}\text{Ni}(^{12}\text{C}, np)$	from $^{63}\text{Cu}(^{10}\text{B}, 2np)$	
(1)	(2)	(3)	(4)	(5)
29.8		10(3) ^{a)}		
34.7		3(1) ^{a)}		
57.2		4(2) ^{a)}		
64.5		3(1) ^{a)}		
76.1	41(8)	45(5)	-0.23(1)	0.01(2)
81.3	156(12)	140(10)	-0.18(1)	-0.01(2)
95.2		4(1) ^{a)}		
134.8	100(8)	100(5)	-0.12(1)	-0.00(1)
167.0	32(4)	20(2) ^{b)}		
221.0		4(1)		
223.4		5(1)		
302.4	46(10)	32(5)	-0.15(1)	-0.01(2)
318.6	117(10)	103(8)	-0.14(1)	-0.01(2)
321.2	108(10)	110(8)	0.28(1)	-0.07(1)
331.7		2(1)		
479.0	35(10)	20(5)	-0.30(8)	0.10(10)
485.4	83(10)	74(10)	0.23(1)	0.01(1)
743.0		13(2)		
788.0	85(10)	80(10)	0.19(3)	0.07(4)

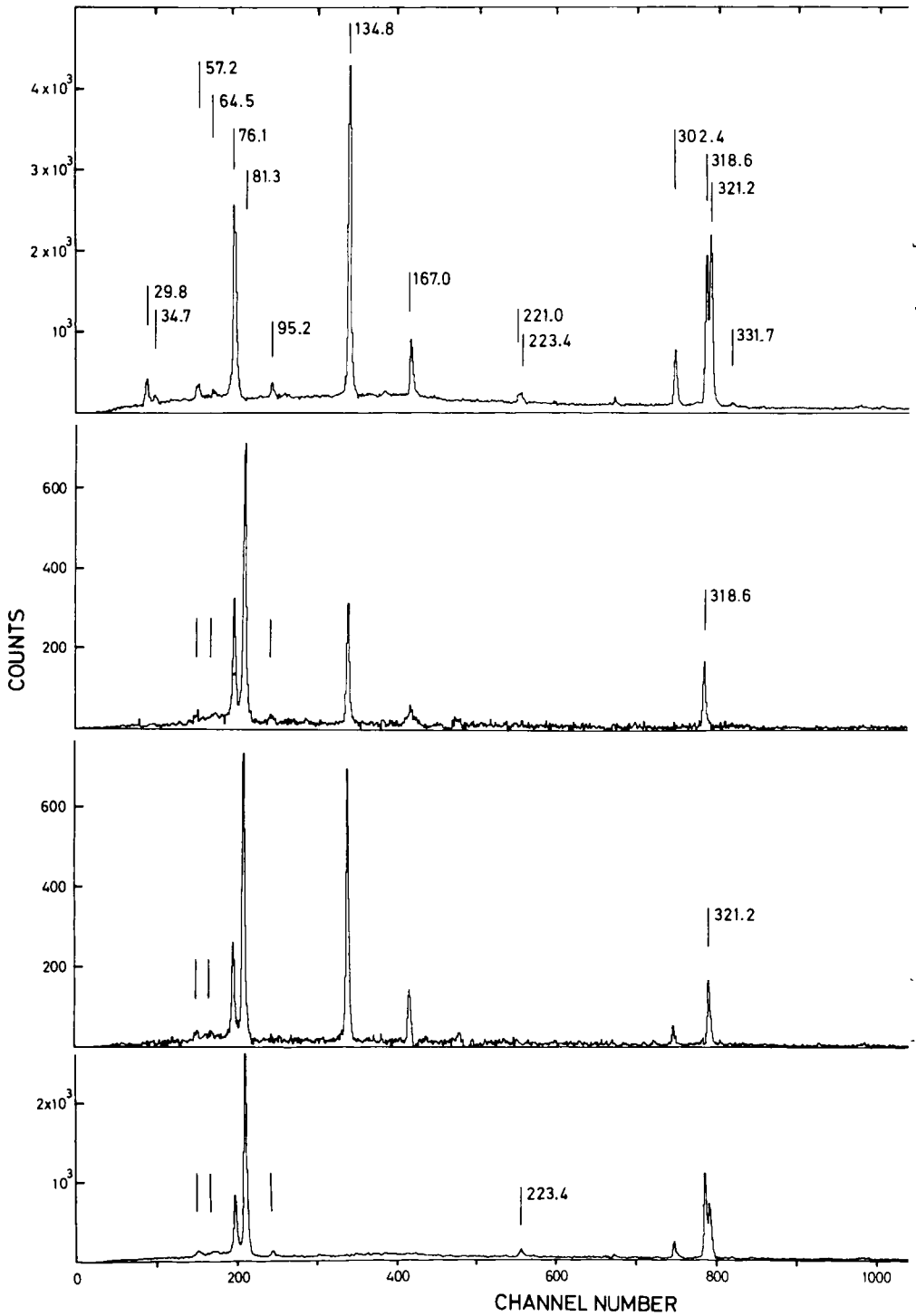
^{a)} Deduced from coincidences with the 81.3 keV γ -ray.

^{b)} Deduced from branching with 134.8 keV γ -ray as seen in coincidence.

The singles γ -ray spectrum from the $^{69}\text{Ga}(\alpha, 3n)$ reaction at 45 MeV, obtained with a 7% efficiency Ge(Li) detector, is shown in fig. 2.

2.2. COINCIDENCE MEASUREMENTS

Coincidence data were recorded using the $^{69}\text{Ga}(\alpha, 3n)$ and $^{60}\text{Ni}(^{12}\text{C}, np)$ reactions at 45 and 50 MeV, respectively, employing pairs of Ge(Li) counters. In both cases one of the detectors was a high-resolution small planar device. The results from the latter experiment are summarized in table 2. The measured coincidence intensities are given, for each gate, in the upper row. These numbers correspond to the peak areas corrected for the efficiency of both counters at the corresponding (γ -ray and gate) energies, and are normalized to the expected intensity of the 318.6 keV peak in the γ -ray spectrum gated with the 134.8 keV γ -ray. The expected value is based on



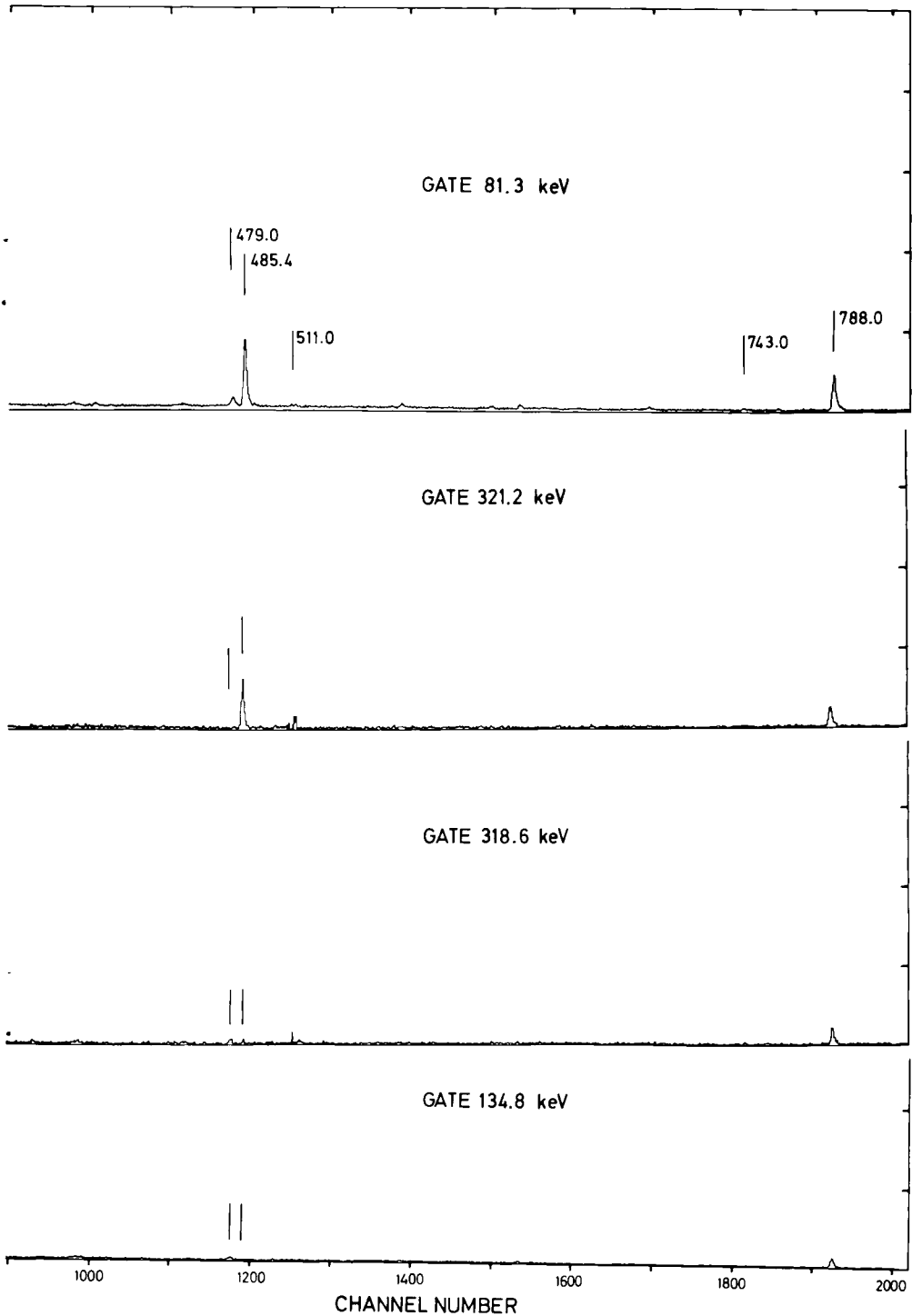


Fig. 3. The γ - γ coincidence spectra obtained by gating the 81.3, 134.8, 318.6 and 321.2 keV lines.

TABLE 2
Coincidence intensities in $^{70}\text{As}^a$

Gate	E_γ	29.8	34.7	57.2	64.5	76.1	81.3	95.2	134.8	167.0	221.0	223.4	302.4	318.6	321.2	331.7	479.0	485.4	743.0	788.0
76.1				2	W	41	2	25	5	2	2	3	20	42		19		3	31	
				(4)		(39)	(1)	(22)	(4)	(4)	(1)	(6)	(25)	(45)		(20)		(6)	(39)	
81.3		8	3	4	2	38	3	65	14	2	2	27	77	97	2	8	58	5	59	
						(39)		(67)	(13)	(4)	(3)	(28)	(80)	(95)	(2)	(17)	(57)	(11)	(69)	
134.8				3	W	23	76	3				6	14	54	W	8			28	
				(2)		(22)	(67)	(3)				(4)	(16)	(53)		(9)			(38)	
302.7		11				6	36	27	5				27			19				
		(10)				(6)	(28)	(15)	(3)				(19)			(13)				
318.6				2	2	34	101	116	23			17	59		6				48	
				(3)	(2)	(26)	(81)	(86)	(18)			(19)	(64)		(10)				(46)	
321.2				W	W	43	99	3	50	9			60		73				56	
						(45)	(95)	(2)	(53)	(11)			(64)		(46)				(80)	
485.4						22	62			W		14	54		5				31	
						(19)	(59)					(14)	(46)		(8)				(33)	
788.0						53	68	48	10			10	52	76		26				
						(40)	(69)	(38)	(8)			?	(46)	(80)		(34)				

^a) The experimental values (upper row) are compared to the expected values (lower row, in parenthesis) obtained by assuming the level scheme of fig. 6. The numbers are normalized to the intensity of the 318.6 keV line in coincidence with the 134.8 keV gate. The letter "W" denotes weak intensities, less than two units.

the singles intensities (column 3, table 1) and the adopted level scheme (see below, fig. 6). The expected values for the other lines are given in parenthesis (lower row). Having corrected for the efficiency of both detectors it is possible to compare each experimental value with its cross-conjugate and an average intensity can be obtained from these pairs of values. The overall agreement between such averages and the expected values is very good. There are only a few cases which deviate more than the estimated error of about 20%. The total intensity of the 81.3 keV transition was estimated by assuming an average between the E1 and M1 theoretical internal conversion coefficients, which for this energy and Z-value are quite similar. In order to establish more firmly the coincidence relationships involving the weaker lines such as the 29.8, 34.7, 57.2, 64.5, 95.2, 221.0, 223.4, 331.7 and 743.0 keV lines, plots obtained by summing several gates were also examined.

Some of the γ - γ coincidence spectra are shown in fig. 3.

2.3. ANGULAR DISTRIBUTION MEASUREMENTS

The γ -ray angular distributions were measured by recording spectra at different angles between 90° and 180° in steps of 15° and at 65° . The $^{63}\text{Cu}(^{10}\text{B}, 2\text{np})$ reaction

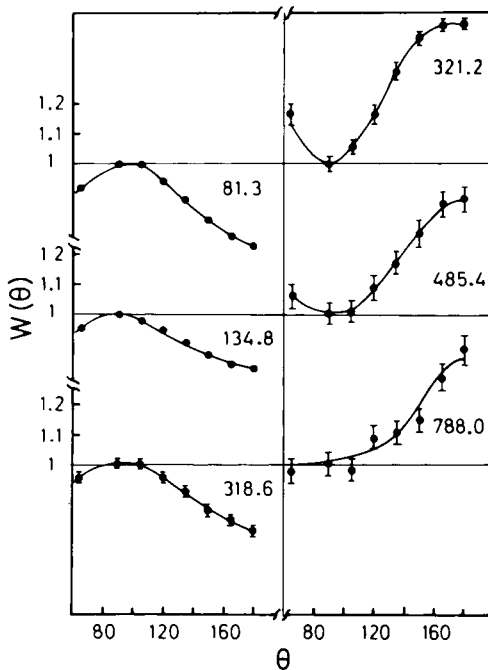


Fig. 4. Angular distribution of some γ -rays of ^{70}As from the $^{63}\text{Cu}(^{10}\text{B}, 2\text{np})$ reaction. The data are normalized to one at 90° . The solid line shows the results of least square fits with the parameters A_2 and A_4 given in table 1.

at 40 MeV was used in this measurement in order to reduce to a minimum the influence of possible attenuating hyperfine fields since Cu has a cubic lattice. The detector was moved about every 10 min for a length of time of approximately 16 h. The normalization was achieved by feeding signals from a selected line in the spectrum recorded with a fixed detector into a counter sensitive to the dead time of the moving detector.

The angular distribution coefficients, obtained by fitting the peak areas to the usual angular distribution function, are shown in columns 4 and 5 of table 1. Some of these fits are also shown in fig. 4.

2.4. HALF-LIFE MEASUREMENTS

A search for isomeric states with lifetimes longer than a few ns was carried out by observing the time correlation between beam bursts and γ -emission. Measurements were performed using the $^{60}\text{Ni}(^{12}\text{C}, \text{np})$ reaction at 50 MeV and a small planar Ge(Li) counter. The system performance yielded a prompt time slope of less than 2 ns.

Half-lives of 4.3 ± 0.2 and 4.5 ± 0.2 ns have been measured for the 81.3 and 321.2 keV lines, respectively, while prompt distributions were observed for the 76.1, 302.7, 479.0 and 788.0 keV transitions. These data together with the information relative to the level scheme (to be discussed below) establish the existence of a 4.4 ± 0.1 ns isomeric state at 887.9 keV, which agrees within errors with previous results¹⁰). It should be noted that the 302.7 keV γ -ray exhibits, in addition to its prompt component, a longer lifetime tail.

The strong 134.8, 318.6, and 485.4 keV lines show a time distribution slope with an apparent half-life of 6.1 ± 0.2 ns. The fact that these lines deexcite levels which are fed by the 4.4 ns isomer (see next section) indicates that such time distributions must be fitted with a double exponential function of the form

$$N = \text{const}[(4.4 \text{ ns}/T_{\frac{1}{2}}) - 1]^{-1} [\exp(-0.693 t/4.4 \text{ ns}) - \exp(-0.693 t/T_{\frac{1}{2}})].$$

The result of fitting the data in this way yields an average value $T_{\frac{1}{2}} = 3.3 \pm 0.7$ ns for the 485.4 keV isomer. The quoted error is estimated so as to include the effect of sidefeeding which has not been taken into account in the fitting procedure. This result agrees within errors with the value 4.5 ± 1.0 ns reported by Ten Brink *et al.*¹⁰).

Fig. 5 shows typical examples of the three main types of time distributions observed; curves (a), (b), and (c) correspond to the data for the 318.6, 321.2, and 788.0 keV γ -rays, respectively.

The 167.0 keV line yields a time distribution with a long-lived component. When this component is subtracted, a slope consistent with a value of 6 ns is obtained. This result is interpreted as an indication that this line appears in singles as a doublet, and that the long half-life is associated to a line which belongs to another nucleus. The measured coincidence intensities indeed show that the 167.0 keV line of ^{70}As is weaker than what appears to be in singles.

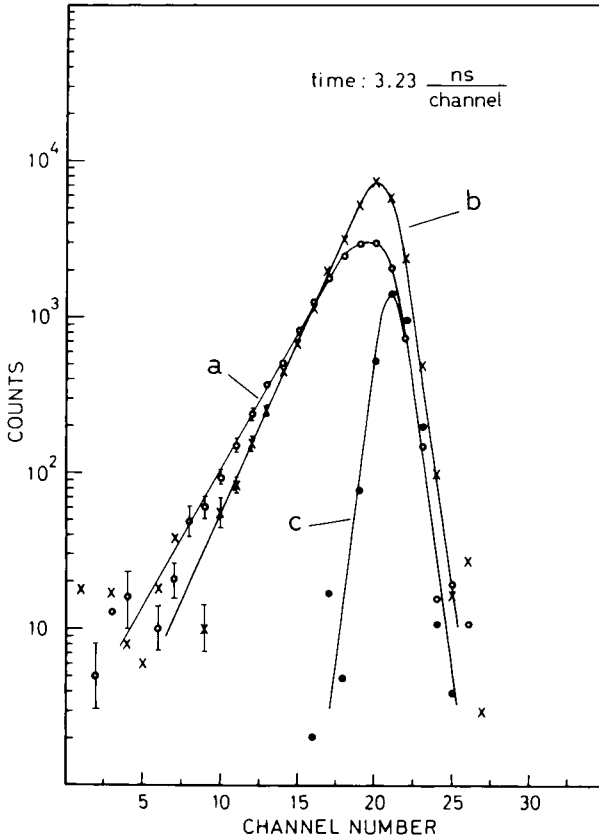


Fig. 5. Time distributions of (a) 318.6, (b) 321.2 and (c) 788.0 keV lines. The curve labeled by (c) shows a typical shape for a prompt peak. The data for the (a) 318.6 keV line shows a larger slope (6 nsc) than that for the (b) 321.2 keV line (4.4 ns) but after subtracting the contribution of the latter (see text) an effective half-life of 3.3 ns is obtained.

3. Energy levels and decay scheme

The energy levels of ^{70}As and their decay scheme are shown in fig. 6. The main path of decay of the residual nucleus involves the 76.1-788.0-321.2-81.3-318.6-134.8 keV cascade. The lower members of this cascade have also been observed in the (p, $n\gamma$) reaction work ¹⁰). However, the low-spin states ($J \leq 2$) above 32.0 keV, seen in both the (p, $n\gamma$) [ref. ¹⁰)] and radioactive decay studies ⁸), have not been observed in this work.

The observed half-life of 4.4 ± 0.1 ns has been assigned to the 887.9 keV level and its value lies close to the expected value for a single-particle E2 transition ¹²). This result is consistent with the measured angular distributions which indicate that the 321.2 keV isomeric transition is a stretched quadrupole.

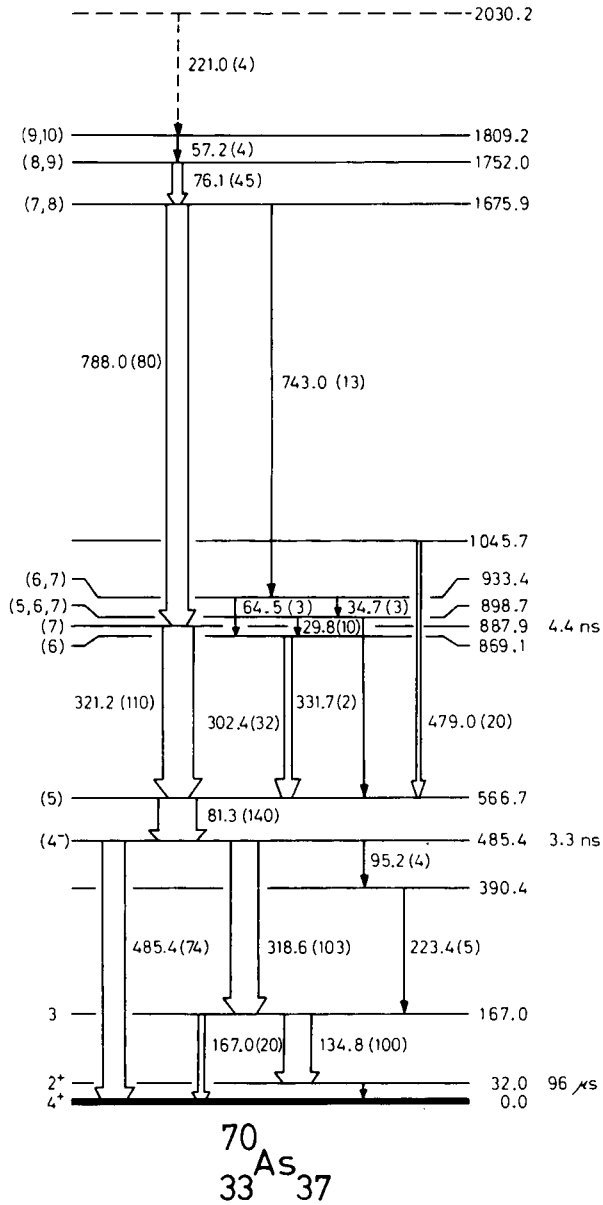


Fig. 6. Level scheme for ^{70}As as proposed in this work. The half-life and decay of the 32.0 keV state is taken from ref. ¹⁰).

The ground- and first-excited states are known to be 4^+ and 2^+ , respectively ^{5, 8, 10}). The 167.0 keV state corresponds to the lower member of the multiplet seen by Ten Brink *et al.* ¹⁰) at about this energy. These authors tentatively assign $J = 2$ or 3

to this state. The angular distribution of the 134.8 keV γ -ray is, in our case, indicative of a $\Delta J = 1$ transition, so that we conclude that $J(167.0) = 3$.

The 485.4 keV level decays to the 4^+ ground state, and to the 167.0 keV state via the 318.6 keV transition and the weaker 95.2-223.4 keV cascade. The angular distribution of the 318.6 keV γ -ray shows $\Delta J = 1$ character so that $J(485.4) = 2$ or 4 .

This ambiguity is not readily solved by taking into account the measured $A_2^{e_{xp}}$ and $A_4^{e_{xp}}$ coefficients for the 485.4 keV line (see table 1) since their values are consistent with a $\Delta J = 0, 1$ or 2 transition. However, the possibility $\Delta J = 2$ implies a negligible amount of attenuation in the angular distribution of this transition [i.e., $A_2^{\text{max}}(2 \rightarrow 4) = 0.20$, ref. ¹³], as compared with $A_2^{e_{xp}} = 0.23 \pm 0.01$], while the angular distribution of the preceding 321.2 keV stretched quadrupole transition indicates that $\alpha_2 = A_2^{e_{xp}}/A_2^{\text{max}}$ lies between 0.5 and 0.64. Since one expects α_2 to decrease, rather than increase, as the nucleus is deexcited, the possibility $J(485.4) = 2$ is ruled out, leaving $J = 4$ as the most likely possibility for this level. Further, the lifetime of this level indicates a substantial amount of hindrance for the two more intense dipole transitions which depopulate it. If this state had positive parity, an E2 transition to the first 2^+ state at 32.0 keV could be expected with reasonable intensity since the single-particle strength yields a partial half-life of about 1 ns. However, the intensity of the unobserved 453.4 keV γ -ray is less than $0.02I_\gamma(485.4)$. This implies an unusual hindrance for E2 transitions, which cannot be ruled out, but makes a positive parity assignment unlikely. In view of these arguments we tentatively propose $J^\pi(485.4) = (4^-)$.

The 81.3 keV γ -ray angular distribution corresponds to a $\Delta J = 1$ transition leading to $J = 3$ or 5 for the 566.7 keV state. The latter value is favored on account of the fact that crossover transitions from this (or upper states) are not observed, thus suggesting an increasing sequence of spin values with energy.

The 566.7 keV state is mainly populated by the 321.2 keV isomeric transition which we identify, as mentioned above, with a stretched E2 transition, on the basis of its half-life and angular distribution, and consequently its spin is proposed as $J = (7)$. The weaker 302.4 and, more tentatively, the 479.0 keV transitions feed, as indicated by the coincidence data, the 566.7 keV state. Intensity balance for this level is achieved if the internal conversion coefficient for dipole radiation ($\alpha_T \approx 0.13$ (E1) or 0.15 (M1)) is taken into account for the 81.3 keV transition. In view of the negative anisotropy of the 302.7 keV line, the 869.1 keV level is tentatively assigned spin $J = (6)$.

The 29.8 keV γ -ray appears strongest in the spectrum gated with the 302.4 keV peak, and has been placed feeding the 869.1 keV state. It is difficult to determine its intensity with accuracy since the detector efficiency is not well established at such low energies, but, within errors, our estimate yields a good intensity balance once internal conversion is taken into account (assuming dipole character). A good energy fit is also obtained with the 331.7 keV crossover transition. Ten Brink *et al.* ¹⁰) also see the transition which they placed similarly in their level scheme. The weak 34.7 keV

γ -ray is only observed in coincidence with the strong 81.3 keV line, while the 64.5 keV γ -ray is also observed in the spectrum gated with the other prominent peaks at 134.8, 318.6, and 485.4 keV. Because of the energy fit the 34.7 and 64.5 keV lines are interpreted as transitions depopulating a new level at 933.4 keV. It is possible that the tail observed in the time distribution of the 302.4 keV originates in the 898.7 and/or 933.4 keV levels.

The 743.0 keV radiation is seen in coincidence with the 81.3 and 76.1 keV γ -rays. On this basis, and taking into account the energy fit obtained, this line is placed as indicated in fig. 6. It provides an answer to the earlier puzzle presented by the observation of a weak coincidence relationship between the 76.1 and the 302.4 keV lines.

The 57.2 and 221.0 keV γ -rays are seen in coincidence with all the gates although very weakly in those cases involving gates corresponding to the lowest-lying transitions. In view of their intensities these are placed above the 76.1 keV transition, feeding the 1752.0 keV state. Since the analysis of the 221.0 keV line is somewhat obscured by the fact that it is not clearly resolved from the 223.4 keV peak, the placement of this transition is regarded as tentative. The expected internal conversion contribution to the total transition intensity favors the placement of the 57.2 keV γ -ray below the 221.0 keV γ -ray.

The spin of the 933.7 keV state is probably limited to $J = 5, 6, 7$ since the 64.5 keV line is expected to be dipole radiation as it competes with the 34.7 keV γ -ray. Furthermore, the time distribution of the 302.4 keV γ -ray is not consistent with a long-lived feeding such as it should be observed if the 64.5 keV line was a quadrupole transition.

The tentative assignments for the 1675.9, 1752.0, and 1809.2 keV levels are based on the angular distributions of the 743.0, 788.0, and 76.1 keV lines (which exhibit $\Delta J = 1, \Delta J = 0, 1$ or 2 and $\Delta J = 1$ character, respectively), the deduced dipole character of the 57.2 keV line (from the timing of both 76.1 and 788.0 keV γ -rays), and the non-observation of crossover transitions to the lower-lying states.

Further, if we assume the assignment $J = (5)$ given in ref. ¹⁶⁾ for the spin of the 898.1 keV level we obtain $J = (6), (7), (8)$ and (9) for the spins of the 933.4, 1675.9, 1752.0 and 1809.2 keV states, respectively.

4. Discussion

The present work reports on relatively high-spin states of ⁷⁰As, providing complementary information to that previously obtained through radioactive and $(p, n\gamma)$ reaction studies ^{8, 10)}. Some of these states were also observed in the $(p, n\gamma)$ work ¹⁰⁾ and although spin-parities were not determined, it was suspected that they should be high-spin states, probably arising from the $\{\pi f_{7/2}, \nu g_{7/2}\}$ configuration. This configuration represents the predominant contribution to the ground states of the heavier As isotopes.

Although the structure of an odd-odd nucleus eludes, in general, a simple description, it is reasonable to expect that low-lying high-spin states can be more

easily understood either as collective states or as states with contributions from few shell-model configurations.

In the case of ^{70}As , the results of this work do not seem to reveal strong collective features in this nucleus. No band structure, such as that observed ⁶⁾, for instance, in the next lighter doubly odd isotone ^{68}Ga is found. At the same time, the half-life of the 887.9 keV isomer lies close to the single-particle estimate, and very small mixing ratios are deduced from the angular distribution data. It may therefore be expected that the present level scheme should find an adequate description within the framework of the shell model.

With $Z = 33$ and $N = 37$, the properties of the ^{70}As ground state should be closely given by the coupling of a proton and a neutron in the p-f subshell, in accordance with the fact that the ground states of the odd- Z ^{69}As and ^{71}As and odd- N ^{69}Ge and ^{71}Se isotopes have all $J^\pi = \frac{5}{2}^-$.

For the $\{\pi f_{7/2}, \nu f_{7/2}^{-1}\}$ configuration, the Brennan and Bernstein rules ¹⁴⁾ predict the $J^\pi = 4^+$ state to lie lowest, as is experimentally observed. Furthermore, the measured half-life ¹⁰⁾ of the first 2^+ state at 32.0 keV is consistent with the assumption that this state also is a member of the same multiplet.

More information on the next two states at 167.0 and 390.4 keV must be obtained before their structure can be discussed. From the calculations of Kimura *et al.* ⁴⁾, the former could be the 3^+ member of the $\{\pi f_{7/2}, \nu f_{7/2}^{-1}\}$ multiplet if its parity is determined to be positive.

The (4^-) and (5) states at 485.4 and 566.7 keV, when viewed together with the proposed (6) state at 869.1 keV, exhibit a pattern which is also found ^{1,2)} in ^{72}As and ^{74}As . In ^{72}As a $6^- \rightarrow 5 \rightarrow 4^-$ cascade is observed with 200.1 \rightarrow 53.0 keV transition energies while in ^{74}As there is a $(6) \rightarrow (5^-) \rightarrow (4^-)$ cascade with 211.6 \rightarrow 63.84 keV transition energies. The regularity of the transition energies when compared with those in ^{70}As is suggestive of a similar origin for the three cascades. It is found that the excitation energies of the 4^- states in these cascades are similar to the $\frac{9}{2}^+$ state energies in the corresponding isotones of Zn and Ge, roughly following the same behavior when plotted against neutron number. It seems therefore possible to identify these states with the excitation of the unpaired neutron into the $g_{7/2}$ orbit, as the 4^- member of the resulting multiplet lies close to its center of gravity ⁴⁾.

At about 1 MeV a group of closely spaced levels is observed. This energy is similar to the energy where the first $\frac{9}{2}^+$ state in ^{71}As is found, so that some of these levels may be due to the promotion of the last proton to the $g_{7/2}$ orbit.

Finally, the highest-lying groups of levels observed in this work may arise from the coupling of a $g_{7/2}$ proton and a $g_{7/2}$ neutron since their energy agrees with that deduced from the energies of the odd- A neighbor. Alternatively, these levels may originate in the coupling of a $g_{7/2}$ neutron to excitations of the even-even core, similar to the first 2^+ state in ^{68}Ge which lies at 1016 keV. It is probable that the $\frac{1}{2}^+$ and $\frac{1}{2}^+$ states observed in ^{69}Ge at about 1.5 MeV correspond to this description.

More data are required in order to establish the validity of the proposed con-

figurations, but the information presently available appears to show at least consistency with a picture in which the p-n interaction is not strong enough to obscure the basic features obtained by assuming the simplest coupling between the states of the odd- A neighbors. Such a possibility, which seems to emerge also from other recent investigations of doubly odd nuclei in this region ⁶⁾, as well as others ¹⁷⁾, warrants further investigation.

References

- 1) M. A. J. Mariscotti, M. Behar, A. Filevich, G. García Bermúdez, A. M. Hernandez and C. Kohan, Nucl. Phys. **A260** (1976) 109
- 2) G. García Bermúdez, M. Behar, A. Filevich and M. A. J. Mariscotti, Phys. Rev. **C14** (1976) 1776
- 3) H. Bertschat, H. Kluge, H. Leithauser, E. Recknagel and B. Spellmeyer, Nucl. Phys. **A249** (1975) 93
- 4) K. Kimura, N. Takagi and M. Tanaka, Nucl. Phys. **A272** (1976) 381
- 5) A. P. De Ruiter, H. Verheul and I. Konijn, Nucl. Phys. **A116** (1968) 473
- 6) M. Behar, A. Filevich, G. García Bermúdez and M. A. J. Mariscotti, Nucl. Phys. **A282** (1977) 331
- 7) M. Behar, A. Filevich, G. García Bermúdez and M. A. J. Mariscotti, Nucl. Phys. **A283** (1977) 12
- 8) B. O. ten Brink, R. D. Vis, A. W. B. Kalshoven and H. Verheul, Z. Phys. **270** (1974) 83
- 9) I. L. Preiss, Technical Progress Report COO-3464-10
- 10) B. O. ten Brink, P. van Hess, C. Hoetmer, T. J. Ketel and H. Verheul, Int. Conf. on nuclear structure, Tokyo, Japan, 1977, p. 279
- 11) A. Filevich, M. Behar, G. García Bermúdez and M. A. J. Mariscotti, Int. Conf. on nuclear structure, Tokyo, Japan, 1977, p. 278
- 12) C. M. Lederer, J. M. Hollander and I. Perlman, Table of isotopes (Wiley, New York, 1967) p. 578
- 13) E. der Mateosian and A. W. Sunyar, Nucl. Data Tables **13** (1974) 391
- 14) M. H. Brennan and A. M. Bernstein, Phys. Rev. **120** (1960) 927
- 15) K. Kimura and N. Takasi, Int. Conf. on nuclear structure, Tokyo, Japan, 1977, p. 288
- 16) B. O. ten Brink, Thesis, Vrije Universiteit te Amsterdam (1978) p. 50
- 17) A. J. Kreiner, M. Fenzl, S. Lunardi and M. A. Mariscotti, Nucl. Phys. **A282** (1977) 243