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INVESTIGATION OF THE LEVEL SCHEMES OF ^{73,75,77}As VIA THE (^{3}He, d) REACTION

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Abstract: The reactions ^{72,74,76}Ge(^{3}He, d) were investigated at $E_{lab} = 23$ MeV with a multigap and a Q3D magnetic spectrograph. Some 30 new levels up to $E^* \approx 4$ MeV have been found. The level schemes of the odd As isotopes ^{73,75,77}As up to $E^* \approx 4$ MeV seem to be rather independent of the neutron number. The good agreement of the low-lying level structure with the Coriolis-coupling model including a pairing force was verified and the vacancies of low-lying shell model states were extracted and compared with the simple pairing theory.

E | NUCLEAR REACTIONS ^{72}Ge(^{3}He, d), ^{74}Ge(^{3}He, d), ^{76}Ge(^{3}He, d), $E = 23$ MeV; measured $\sigma(E_d, \theta)$; deduced Q. ^{73}As, ^{75}As, ^{77}As deduced levels, l_p, $(2J+1)C^2S$. Enriched targets.

1. Introduction

First results have been published [1]) for the present investigation of the ^{72,74,76}Ge(^{3}He, d) reactions. Relatively little information, limited to a few low-lying levels, was available previously concerning the ^{73,75,77}As nuclei. Several theoretical attempts [2–9]) have been made to describe the level schemes of these nuclei. A very sensitive test of these models is the ordering of low-lying positive parity states. The model of statically prolate deformed nuclei with Coriolis coupling and a pairing interaction is the only one that has been able to describe the previously known structure of low-lying levels [10]). This model also agrees well with low-lying negative parity states found in a recent investigation [11]) of odd As isotopes with the (^{3}He, d) reaction at $E_{lab} = 15$ MeV.

In the present investigation with the (^{3}He, d) reaction at $E_{lab} = 23$ MeV, it was possible to resolve clearly all levels with $E^* \lesssim 1$ MeV using a Q3D magnetic spectrograph. The results agree well with the Coriolis-coupling model with pairing interaction of Malik and Scholz [6]). Furthermore, with a bombarding energy of $E_{lab} = 23$ MeV, well above the Coulomb barrier, we extended the previous investigations with $E_{lab} = 15$ MeV [ref. [11])] to higher excitation energies. This knowledge of the spectroscopic factors of highly excited levels is needed to find all components of antianalogue states in our investigations [12,13]) of analogue states in odd As isotopes. Furthermore, with these spectroscopic results it was possible to compare the level

structure of different odd As isotopes up to $E^* \gtrapprox 3$ MeV, and to compare the occupation of low-lying proton orbits in ^{72,74,76}Ge with the simple pairing theory.

2. Experimental procedure

The ^{72,74,76}Ge targets were prepared by reduction of germanium oxide in a hydrogen atmosphere and evaporation of the resulting germanium onto thin carbon backings. The isotopically enriched targets of 90.9 % ^{72}Ge (46 μg/cm^2), 96.1 % ^{74}Ge (18 μg/cm^2) and 84.7 % ^{76}Ge (46 μg/cm^2) were bombarded with a 300 nA beam of ^{3}He^{++} ions at 23 MeV, obtained from the Heidelberg Tandem Van de Graaff accelerator "Emperor".

To investigate the energy spectra and angular distributions of the deuterons resulting from the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions, runs with two different experimental arrangements were performed for each isotope:

(a) In order to determine the spectroscopic factors of individual low-lying levels not resolved in previous (^{3}He, d) studies, an energy resolution of better than 20 keV was needed. Therefore we analyzed the outgoing deuterons with a Q3D magnetic spectrograph [14]) with 3 msr solid angle at $\theta_{lab} = 25°$. Furthermore we measured an angular distribution of the ^{76}Ge(^{3}He, d)^{77}As reaction with $\theta_{lab} = 7°$, 10°, 13°, 16°, 19° and 23° and with a solid angle of 1 msr. Because of the large dispersion of the Q3D spectrograph, the deuteron spectra ranged from the ^{73,75,77}As ground states up to 1.1 MeV excitation energy. A resistive wire proportional counter [15]) with 40 cm sensitive length was used as detector. To correct for the kinematic broadening by the magnetic multipole element, we used the high intensity elastically scattered ^{3}He^{++} ions, which had the same kinematic shift as the investigated deuterons at a particular angle. This procedure was similar to that used in the first experiment performed with a Q3D magnetic spectrograph [16]). With this method an energy resolution of 14 keV FWHM was obtained for the d-peaks, the limitation being mainly due to the detector. A test with a position-sensitive surface barrier detector gave a resolution of ≈ 6 keV corresponding to $\Delta E/E < 3 \times 10^{-4}$.

(b) In order to reach higher excitation energies, spectra were taken with a multigap magnetic spectrograph with 0.37 msr solid angle. Ilford K2 nuclear emulsion plates of 50 μm thickness were used as detectors. The plates were scanned in steps of 0.5 mm and the energy resolution was about 25–30 keV. The measured angular distributions ranged from $\theta_{lab} = 5.5°$ to 50.5°. The angle θ_{lab} was varied in alternating steps of $\Delta\theta_{lab} = 4.0°$ and 3.5° for ^{73}As, in steps of $\Delta\theta_{lab} = 7.5°$ for ^{75}As and in alternating steps of $\Delta\theta_{lab} = 2.0°$ and 5.5° for ^{77}As. The highest excitation energies observed were 3.2 MeV in ^{73}As, 3.8 MeV in ^{75}As and 4.5 MeV in ^{77}As.

The absolute cross sections for the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions were established in a subsidiary experiment by comparing the counting rate of the elastic ^{3}He^{++} line scattered in natural germanium with the deuterons from the (^{3}He, d) reactions on the ^{72,74,76}Ge portions at $\theta_{lab} = 13°$ and $E_{lab} = 23$ MeV.

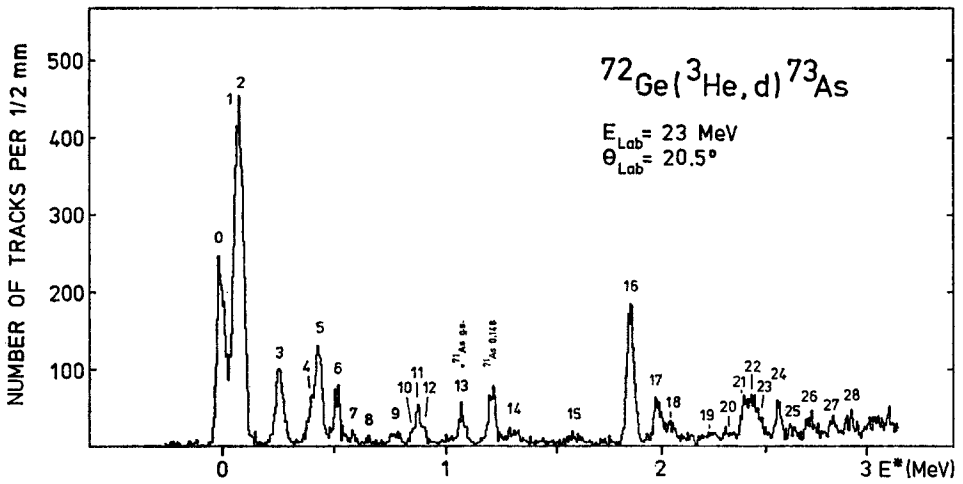

Fig. 1. Spectrum of the reaction ^{72}Ge(^{3}He, d)^{73}As measured at $\theta_{lab} = 20.5°$ with a multigap magnetic spectrograph.

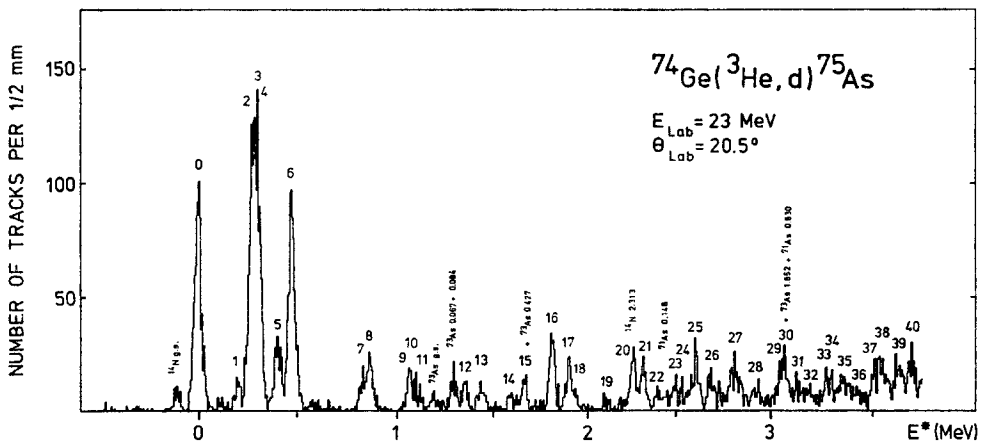

Fig. 2. Spectrum of the reaction ^{74}Ge(^{3}He, d)^{75}As measured at $\theta_{lab} = 20.5°$ with a multigap magnetic spectrograph.

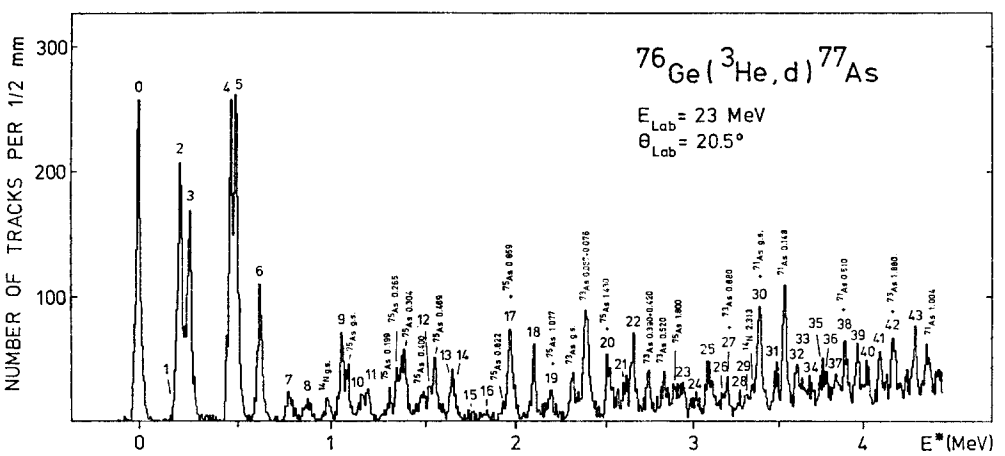

Fig. 3. Spectrum of the reaction ^{76}Ge(^{3}He, d)^{77}As measured at $\theta_{lab} = 20.5°$ with a multigap magnetic spectrograph.

3. The (^{3}He, d) reaction Q-values

The Q-values of the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions to the ground states were determined by comparing the ^{73,75,77}As g.s. deuteron lines at several angles with the deuterons from the ^{13}C(^{3}He, d)^{14}N reaction in the thin carbon backing. The g.s. Q-value of $Q = 2056.91 \pm 0.27$ keV for the latter reaction is well known [17]).

With due regard to the stopping powers in carbon and germanium, the (^{3}He, d) Q-values were established to be $Q = 160 \pm 4$ keV on ^{72}Ge, $Q = 1414 \pm 4$ keV on ^{74}Ge and $Q = 2497 \pm 3$ keV on ^{76}Ge, respectively. A comparison with $Q = 169 \pm 15$

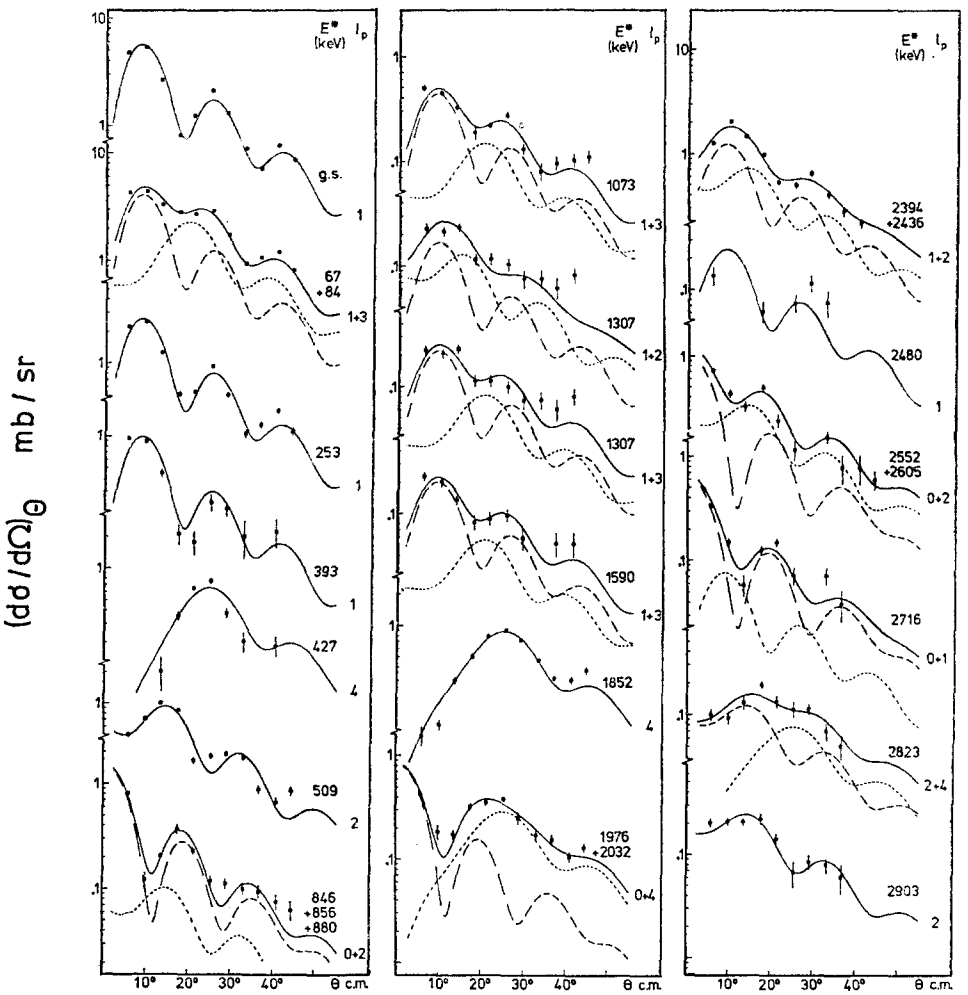

Fig. 4. The ^{72}Ge(^{3}He, d)^{73}As angular distributions measured with the multigap spectrograph and the corresponding DWBA fits ($E_{lab} = 23$ MeV). The angular distributions of distinct unresolved levels are represented by dotted lines.

keV on ^{72}Ge, $Q = 1402.7 \pm 2.5$ keV on ^{74}Ge and $Q = 2501 \pm 9$ keV on ^{76}Ge from calculations of mass differences [17]) shows good agreement in the cases of ^{72,76}Ge, but a discrepancy in the ^{74}Ge case.

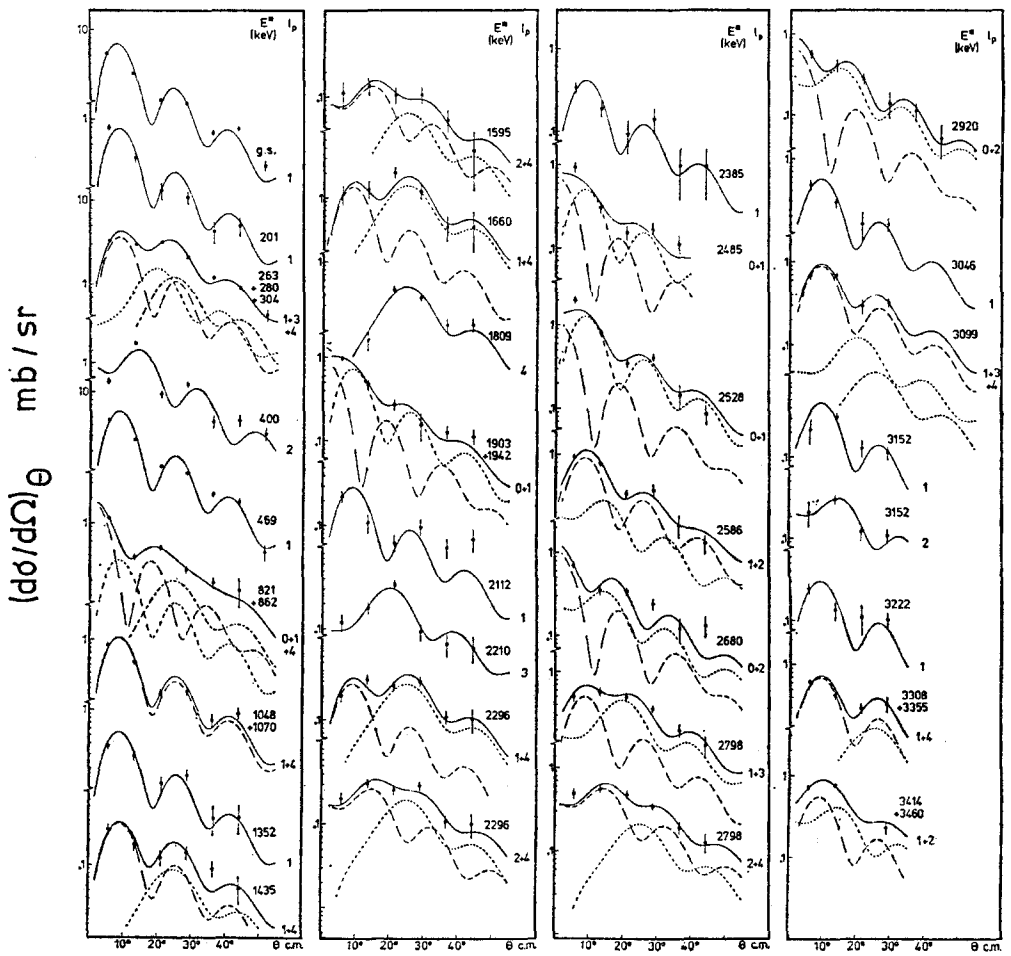

Fig. 5. The ^{74}Ge(^{3}He, d)^{75}As angular distributions measured with the multigap spectrograph and the corresponding DWBA fits ($E_{lab} = 23$ MeV). The angular distributions of distinct unresolved levels are represented by dotted lines.

4. Experimental results and DWBA analysis

Deuteron spectra from the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions with $E_{lab} = 23$ MeV at $\theta_{lab} = 20.5°$ measured with the multigap spectrograph are shown in figs. 1, 2 and 3. The spectra were analyzed with a multi-peak fitting program. Deuteron groups originating from the investigated Ge isotopes are labelled numerically if they ap-

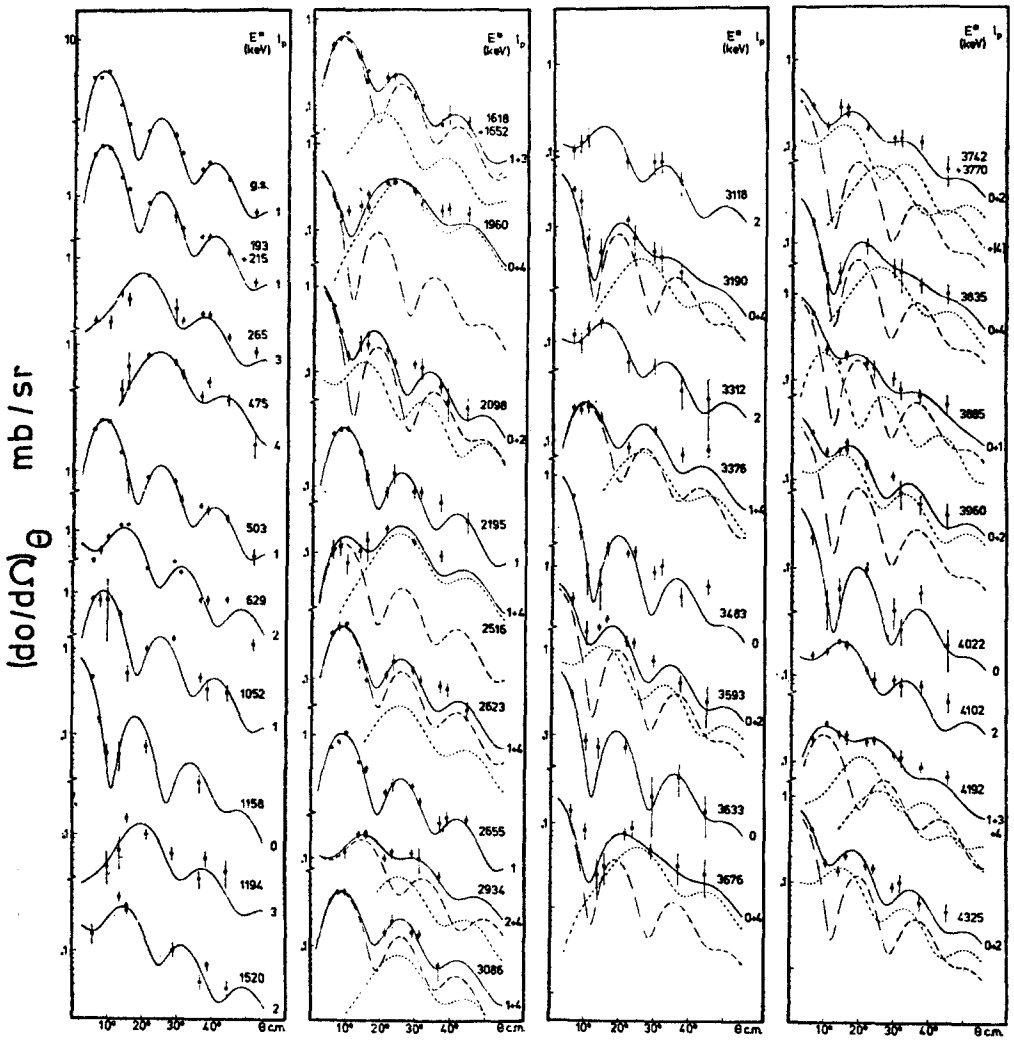

Fig. 6. The ^{76}Ge(^{3}He, d)^{77}As angular distributions measured with the multigap spectrograph and the corresponding DWBA fits (E_{lab} = 23 MeV). The angular distributions of distinct unresolved levels are represented by dotted lines.

peared in more than four spectra at different angles. Groups due to contaminants are marked according to their final states in the residual nuclei. Peaks from ^{70}Ge contaminants were identified by comparison with lines from the (^{3}He, d) reaction on this isotope, which has been measured under identical experimental conditions. The impurity peaks arising from the ^{13}C(^{3}He, d)^{14}N reaction could be recognized easily by their characteristic displacement with angle.

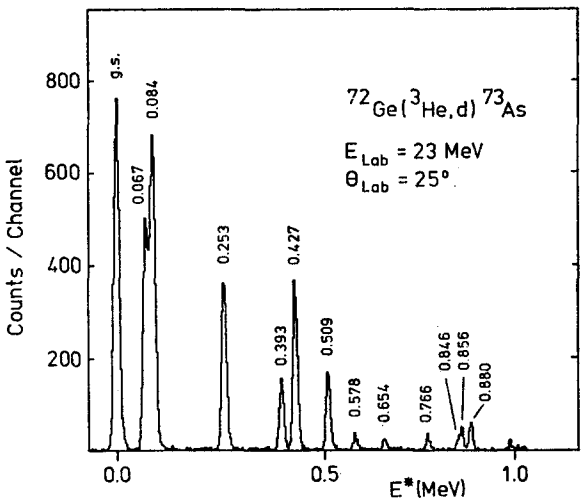

Fig. 7. Spectrum of the reaction ^{72}Ge(^{3}He, d)^{73}As measured at $\theta_{lab} = 25°$ with the Q3D spectrograph.

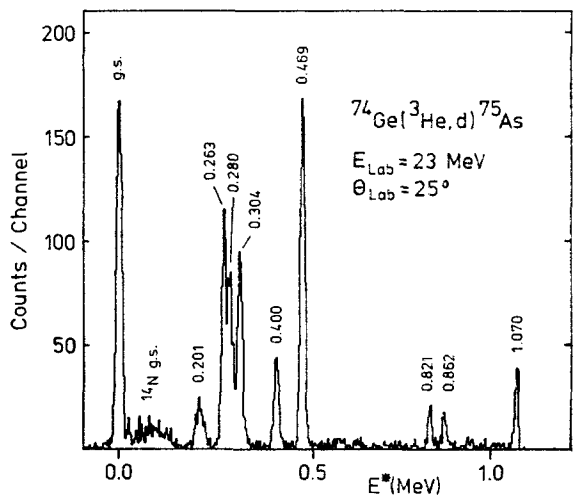

Fig. 8. Spectrum of the reaction ^{74}Ge(^{3}He, d)^{75}As measured at $\theta_{lab} = 25°$ with the Q3D spectrograph.

The resulting angular distributions are shown in figs. 4–6. The error bars in those figures are due to statistics and background subtraction. Errors in the absolute cross sections are estimated to be smaller than 15 %.

Deuteron spectra measured with the Q3D magnetic spectrograph at $\theta_{lab} = 25°$ are shown in figs. 7–9. In these spectra all states below $E_x = 1$ MeV except the weak peak in ^{77}As at $E_x = 0.193$ MeV are clearly separated for the first time in a (^{3}He, d) investigation of odd As isotopes. The large width of the ^{14}N g.s. peak compared to the ^{75}As peaks in fig. 8 arises from kinematic broadening due to the large solid angle.

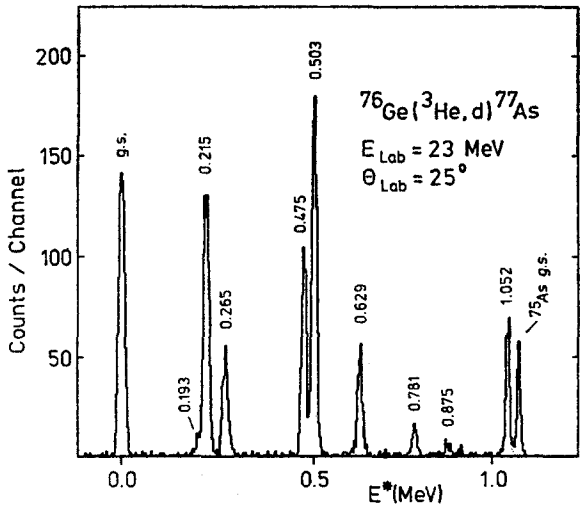

Fig. 9. Spectrum of the reaction ^{76}Ge(^{3}He, d)^{77}As measured at $\theta_{lab} = 25°$ with the Q3D spectrograph

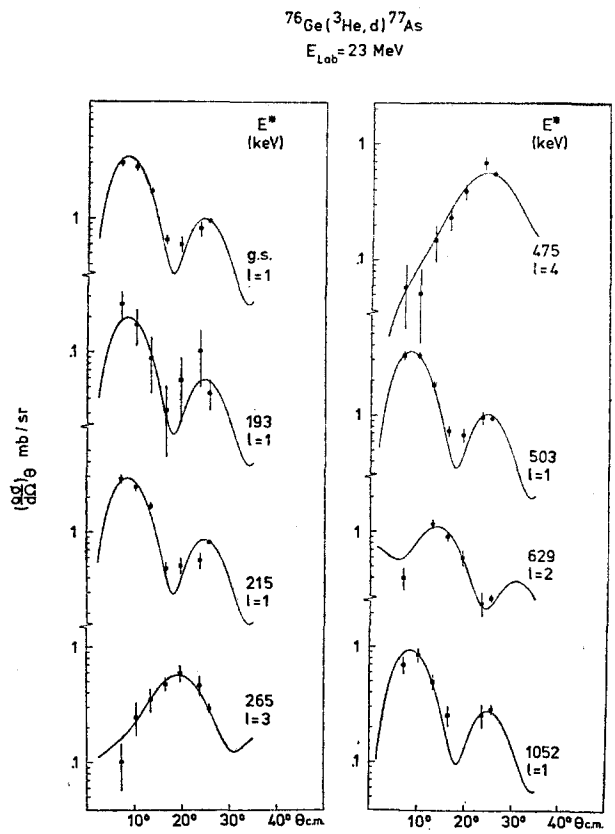

Fig. 10. The ^{76}Ge(^{3}He, d)^{77}As angular distributions with the corresponding DWBA fits measured with the Q3D spectrograph.

The angular distributions of the ^{76}Ge(^{3}He, d)^{77}As reaction extracted from the Q3D spectra are shown in fig. 10. It was not possible to get angular distributions for the E_x = 0.781 and 0.875 MeV states because they were obscured at most angles by the very broad ^{13}C(^{3}He, d)^{14}N g.s. deuteron group.

TABLE 1

Optical-model potentials used (see text) in the analysis of the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions at E_{lab} = 23 MeV

	V (MeV)	r_0 (fm)	a (fm)	W (MeV)	W_d (MeV)	r'_0 (fm)	a' (fm)	$V_{s.o.}$ (MeV)	r_{0c} (fm)	Ref.
	177.8	1.14	0.72	25.7		1.54	0.80		1.40	[18]
	154.9	1.20	0.72	40.2		1.40	0.88		1.30	[30]
^{3}He	80.0	1.30	0.70	15.0	0	1.55	0.80	0	1.40	[31]
	59.7	1.57	0.60	15.0		1.57	0.60		1.30	[32]
	175.0	1.14	0.72	15.0		1.60	0.81		1.40	[33]
	92.7	1.15	0.81		19.6	1.34	0.68		1.15	[18]
	91.1	1.15	0.81		19.9	1.34	0.68		1.15	[34]
	55.8	1.15	0.87		14.2	1.37	0.70		1.15	[34]
d	91.7	1.15	0.81	0	19.4	1.34	0.68	0	1.15	[34]
	43.8	1.30	0.79		14.5	1.37	0.67		1.30	[34]
	72.9	1.30	0.73		20.9	1.34	0.65		1.30	[34]
		1.20	0.65						1.25	[18]
p	[a]	1.17	0.75	0	0	0	0	[b]	1.25	[35]
		1.25	0.65						1.25	[36]

[a] Adjusted to give the transferred proton a binding energy $B_p = Q(\gamma, p) - E^*$.

[b] The spin-orbit part of the bound-state potential was proportional to V and its strength was 25 times the Thomas value.

Distorted-wave calculations were performed using the code DWUCK and fitted absolutely to the measured angular distributions. Woods-Saxon potentials of the form

$$V(r) = -V(1+e^{x})^{-1} - i\left[W - 4W_d\left(\frac{d}{dx'}\right)\right](1+e^{x'})^{-1} + V_C(r, r_c),$$

with $x = (r - r_0 A^{\frac{1}{3}})/a$ and $x' = (r - r'_0 A^{\frac{1}{3}})/a'$ were used for the entrance and exit channels as well as for the proton bound state. In the latter, a spin-orbit coupling term was also included. Different combinations of optical parameters for ^{3}He, d and p, given in table 1, have been tried in order to fit the experimental angular distributions. The best fits have been obtained with the parameters given in ref. [18]). These have been used in the final analysis. The spectroscopic strengths $(2J_f+1)C^2S$ have been obtained from the relation

$$\rho_{exp}(\theta) = N\frac{2J_f+1}{2J_i+1}C^2S\,\frac{2s+1}{2}\,\frac{\rho_{DWBA}(\theta)}{2J+1},$$

TABLE 2

Summary of results for the ^{72}Ge(^{3}He, d)^{73}As reaction

Present investigation (E_{lab} = 23 MeV)				J^{π} [a]	Previous work [b] (E_{lab} = 15 MeV)		
no.	E^* (keV)	l_p	$(2J+1)C^2S$		E^* (keV)	l_p	$(2J+1)C^2S$
0	g.s.	1	0.92	$\frac{3}{2}^-$	g.s.	1	1.03
1	67.5± 0.7	3	5.33	$\frac{5}{2}^-$	72± 7	3	4.92
2	84.2± 0.5	1	0.67	$\frac{3}{2}^-$		1	0.85
3	253.4± 0.5	1	0.47	$\frac{1}{2}^-$	253± 7	1	0.49
4	393.0± 0.8	1	0.17	$\frac{3}{2}^-$	418± 7	1	0.16
5	427.4± 0.5	4	2.42	$\frac{9}{2}^+$		4	2.46
6	509.1± 0.7	2	0.33	$\frac{5}{2}^+$	513± 7	2	0.44
7	578 ± 2			$\frac{5}{2}$	586± 7	3	0.13
8	654 ± 3			$\frac{1}{2}^-$			
9	766 ± 4			$\frac{5}{2}$	776± 7	3	0.22
10	846 ± 4			$\frac{5}{2}$			
11	856 ± 4	0+(2)	0.05+(0.04)				
12	880 ± 4				886± 7	0	0.08
13	1073 ± 5	1+3	0.05+0.18	$\frac{7}{2}$, ($\frac{1}{2}$, $\frac{3}{2}$)	1080± 7		
14	1307 ±10	1+2 or 1+3	0.02+0.04 or 0.03+0.17	$\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}^+$	1323± 7	2	0.08
15	1590 ±15	1+3	0.03+0.12		1599± 7	1	0.04
16	1852 ± 5	4	2.48		1861± 7	4	3.05
17	1976 ± 5	4	0.84		1982± 7	3	0.91
18	2032 ±10	0	0.02		2040±10	0	0.04
19	2220 ±10				2253±10		
20	2311 ±10				2324±10		
21	2394 ±10	1+2	0.16+0.16		2392±10	2	0.22
22	2436 ±10				2443±10	(2)	0.19
23	2480 ±10	(1)	(0.03)				
24	2552 ±10	2	0.08		2562±10		
25	2605 ±10	0	0.02		2609±10	0	0.02
26	2716 ±10	0+1	0.02+0.01		2738±10		
27	2823 ±10	2+4	0.03+0.18		2831±10		
28	2903 ±10	2	0.06		2902±10	2	0.07

The level numbers correspond to the numbers of the deuteron groups in fig. 1.
[a]) Ref. [37]). [b]) Ref. [11]).

between the measured cross section $\rho_{exp}(\theta)$ and the predicted DWBA cross section ρ_{DWBA}, where J_i and J_f denote the spin values of the target nucleus and the final state, J is the total angular momentum and s the spin of the transferred proton, respectively. Further, S is the spectroscopic factor, C is an isospin Clebsch-Gordan coefficient, and the normalization factor N is taken to be 4.42 for a (^{3}He, d) reaction[19]).

The DWBA calculations for the ^{72,74,76}Ge(^{3}He, d)^{73,75,77}As reactions were performed for excitation energies from the ground states up to $E^* = 4.5$ MeV in steps of 0.75 MeV and the intermediate results were extracted by parabolic interpolation. The $3s_{\frac{1}{2}}$ ($l = 0$), $2p_{\frac{3}{2}}$ ($l = 1$), $2d_{\frac{5}{2}}$ ($l = 2$), $2f_{\frac{7}{2}}$ ($l = 3$) and $1g_{\frac{9}{2}}$ ($l = 4$) proton captures are most probable in the shell model and were assumed to determine

TABLE 3

Summary of results for the ^{74}Ge(^{3}He, d)^{75}As reaction

Present investigation (E_{lab} = 23 MeV)				J^{π} [e])	Previous work [f]) (E_{lab} = 15 MeV)		
no.	E^* (keV)	l_p	$(2J+1)C^2S$		E^* (keV)	l_p	$(2J+1)C^2S$
0	g.s.	1	1.42	$\frac{3}{2}^-$	g.s.	1	1.12
1	201.2± 2.4	1	0.19	$\frac{1}{2}^-$	194± 7	1	0.14
2	263.3± 1.3	1	0.82	$\frac{3}{2}^-$	278± 7	1	0.60
3	279.5± 1.7	3	5.45	$\frac{5}{2}^-$		3	3.32
4	303.7± 1.1	4	4.93	$\frac{9}{2}^+$		4	5.20
5	399.7± 1.5	2	0.58	$\frac{5}{2}^+$	396± 7	2	0.52
6	468.9± 1.0	1	1.32	$(\frac{1}{2}^-)$	469± 7	1	0.97
7	821 ± 5	4 or 3	0.80 or 0.60	$\frac{7}{2}^-$	821± 7	3	0.50
8	862 ± 5	0+1 or 2	0.06+0.06	$\frac{1}{2}^+$	868± 7	0	0.10
9	1048 ± 5	3 or 4	0.16 or 0.18	$\frac{7}{2}$			
10	1070 ± 5	1	0.18	$\frac{3}{2}$	1083± 7	1	0.18
11	1131 ±10	0 or 1	0.01 or 0.04	$\frac{1}{2}^{(-)}$	1137± 7	1	0.03
					1297± 7	2	0.18
12	1352 ± 5	1	0.09	$(\frac{1}{2}, \frac{3}{2})$	1359± 7	1	0.13
13	1435 ± 5	1+4	0.06+0.31	$\frac{1}{2}^{(-)}$	1438± 7	1	0.13
14	1595 ±10	2+4	0.04+0.19		1608± 7	1	0.03
15 [a])	1660 ±10	1+4	0.02+0.42	$\frac{1}{2}$	1669± 7	3	0.50
16	1809 ±10	4	1.45	$(\frac{9}{2})^+$	1815± 7	4	1.52
17	1903 ± 5	0	0.02	$\frac{1}{2}^+$	1908± 7	0	0.08
18	1942 ±10	1	0.10				
19	2112 ± 5	(1)	(0.04)	$\frac{1}{2}, \frac{3}{2}^-$	2114±10	1	0.05
20	2210 ±10	3	0.69		2252±10	(3)	(0.43)
21 [b])	2296 ± 5	1+4 or 2+4	0.04+0.81 or 0.07+0.59		2302±10	3	1.36
22	2385 ±10	1	0.04		2389±10	1	0.05
					2446±10	1	0.04
23	2485 ±10	0+1	0.01+0.06		2486±10	1	0.08
24	2528 ±10	0+1	0.02+0.16		2535±10		
25	2586 ± 5	1+(2)	0.11+(0.06)		2597±10	(1)	(0.16)
26	2680 ±10	0+2	0.03+0.08		2673±10		
27 [c])	2798 ± 5	1+3 or 2+4	0.06+0.96 or 0.14+0.59				
28	2920 ± 5	0+2	0.01+0.06				
29	3046 ±10	1	0.06				
30 [d])	3099 ±10	1+3+4	0.10+0.21+0.11				
31	3152 ±10	1 or 2	0.06 or 0.06				
32	3222 ±15	1	0.04				
33	3308 ±10	1+4	0.09+0.39				
34	3555 ±10						
35	3414 ±15	(1+2)	(0.06+0.11)				
36	3460 ±15						
37	3565 ±15	(1)					
38	3608 ±10	(2)					
39	3716 ±10	(1 or 2)					
40	3778 ±10	(1 or 2)					
41	3869 ±10	(1 or 2)					
42	3906 ±10						

The level numbers correspond to the numbers of the deuteron groups in fig. 2.

[a]) Partly ^{73}As E^* = 393 keV l_p = 1 and E^* = 427 keV, l_p = 4. [b]) Partly ^{71}As g.s. l_p = 3?

[c]) Partly ^{71}As E^* = 500 keV l_p = 1.

[d]) l_p = 3: ^{71}As E^* = 830 keV; l_p = 4: ^{73}As E^* = 1852 keV. [e]) Refs. [38,39]). [f]) Ref. [11]).

TABLE 4

Summary of results for the ^{76}Ge(^{3}He, d)^{75}As reaction

Present investigation (E_{lab} = 23 MeV)				J^{π} [g]	Previous work [h] (E_{lab} = 15 MeV)		
no.	E^* (keV)	l_p	$(2J+1)C^2S$		E^* (keV)	l_p	$(2J+1)C^2S$
0	g.s.	1	1.06	$\frac{3}{2}^-$	g.s.	1	0.73
1	192.6± 2.5	1	0.07	$\frac{1}{2}^-$			
2	214.9± 0.8	1	0.81	$\frac{3}{2}^-$	221± 7	1	0.74
3	265.1±1. 5	3	2.15	$\frac{5}{2}^-$	271± 7	3	2.05
4	475.0± 1.3	4	3.73	$\frac{9}{2}^+$	482± 6	7	2.61
5	503.0± 0.9	1	0.82	$(\frac{1}{2}, \frac{3}{2})^-$	514± 7	1	0.76
6	628.6± 1.7	2	0.46	$\frac{5}{2}^+$	631± 7	2	0.34
7	781 ± 5				785± 7		
8	875 ± 5						
9	1052 ± 5	1	0.20		1069± 7	1	0.16
10	1158 ± 5	0	0.03				
11	1194 ± 5	3	0.47	$(\frac{5}{2}, \frac{7}{2})^-$	1201± 7	0	0.04
12	1520 ± 5	2	0.12				
13	1618 ± 5	1+3	0.08+0.22		1674± 7	1	0.08
14	1652 ± 5	or 1+4	or 0.09+0.16				
15	1760 ±10						
16	1825 ±10						
17 [a]	1960 ±10	0+4	0.01+1.09		1988± 7	4	1.17
18	2098 ±10	0+2	0.03+0.04		2118±10	0	0.06
19 [b]	2195 ±10	1	0.07		2212±10		
					2355±10	1	0.05
					2410±10		
20	2516 ±10	4	0.55		2541±10		
21	2623 ±10	1+4	0.05+0.14		2637±10	1+3	0.03+0.30
22	2655 ± 5	1	0.15		2670±10	1	0.12
					2750±10	2	0.07
					2846±10		
23	2934 ±10	2+4	0.04+0.19		2964±10	(1)	0.07
24	3009 ± 5	3 or 4	0.13 or 0.19				
25	3086 ±10	1+4	0.06+0.22				
26	3118 ± 5	2	0.04		3113±10	(1)	0.08
27 [c]	3190 ±10	0+3 or 4	0.01+0.05 or 0.13		3215±10	0	0.02
28	3258 ±10	(1+4)	(0.01+0.08)				
29	3312 ±10	2	0.04				
30 [d]	3376 ±10	1+4	0.03+0.20				
31	3483 ±10	0	0.02		3516±10		
					3559±10	1	0.13
32	3593 ±10	0+2	0.01+0.04				
33	3633 ±15	0	0.02				
34	3676 ±15	0+4	0.01+0.13				
35	3742 ±15	0	0.01				
36	3770 ±15	2+(4)	0.04+(0.14)				
37	3835 ±15	0+4	0.01+0.13				
38 [e]	3885 ±15	0+1	0.02−0.02				
39	3960 ±15	0+2	0.01+0.04				
40	4022 ±20	0	0.01				
41	4102 ±20	2	0.05				
42 [f]	4192 ±20	1+3+4	0.02+0.21+0.10				
43	4325 ±20	0+2	0.02+0.03				

The level numbers correspond to the numbers of the deuteron groups in fig. 3.

[a]) l_p = 0: ^{75}As E^* = 862 keV. [b]) Partly ^{75}As E^* = 1070 keV l_p = 1.

[c]) Partly ^{73}As E^* = 880 keV l_p = 0? [d]) Partly ^{71}As g.s. l_p = 3?

[e]) l_p = 1: ^{71}As E^* = 500 keV. [f]) l_p = 3: ^{71}As E^* = 830 keV; l_p = 4: ^{73}As E^* = 1852 keV.

[g]) Ref. [40]). [h]) Ref. [11]).

the l_p values of the bound states in most of the calculations. Only for levels with known or probable spin $J_f = \frac{1}{2}^-$, $2p_{\frac{1}{2}}$ proton capture was assumed. With the assumption of one, two and three l_p transfers for each level, least χ^2 fits to the experimental angular distributions were performed including all possible combinations of l_p values. The solid curves in figs. 4–6 and 10 are the fits to the angular distributions. The broken lines characterize the individual l_p portions of unresolved levels. It was possible to seperate the weakly excited $E^* = 193$ keV level in ^{77}As from the $E^* = 215$ keV level in the Q3D angular distributions (fig. 10) with a multi-peak fitting program, and thus to determine the l_p value and the spectroscopic factor of this weakly excited state.

A summary of the present experimental results of the ^{72,74,76}Ge(^{3}He, d) reactions is given in tables 2, 3 and 4. The numbers of the numerically labelled levels are equivalent to those in figs. 1, 2 and 3. The level energies with $\Delta E \leqq 0.5$ keV result from the Q3D spectra, whereas the other energies are average values of several multigap spectrograph spectra at different angles. The extracted l_p values and the spectroscopic strengths are given in the third and fourth columns, respectively. Uncertain values are in brackets. In cases of more than one l_p value (unresolved lines) the spectroscopic strengths are specified in the same sequence as the l_p values. The next columns contain previous spin assignments and results from a previous (^{3}He, d) investigation [11]) which both are in good agreement with this work, wherever a comparison can be made.

5. Discussion

A comparison of the levels excited in the (^{3}He, d) investigation of ^{73,75,77}As is shown in fig. 11. The spectroscopic factors S_p of the distinct levels are characterized by the lengths of the thick bars (different scales for different l_p values). The shadowed areas in fig. 11 mark the excitation energies not reached in this investigation.

The striking feature of fig. 11 is the similarity of the level schemes of these As isotopes up to excitation energies of $E^* = 3$–4 MeV. Nearly all levels found in one isotope have corresponding levels in the other investigated As isotopes, sometimes split into several components. These corresponding levels are populated with about the same spectroscopic factors in ^{73,75,77}As. Except for small energy shifts, the level schemes therefore seem to be independent of the neutron number. A similar behaviour has been found, e.g. in the neutron states of $N = 83$ isotones, which are independent of the proton number [20]).

The similarity of the level schemes of the As isotopes can be interpreted by means of the similarity of the level schemes of the Ge target isotopes ^{72,74,76}Ge [ref. [21])], in which the low-lying levels are collective excitations and largely independent of the neutron number. The collective excitations in even Ge isotopes can be explained as vibrational states [22,23]) rather than as rotational states [as, e.g., in Se isotopes [24])]. But besides calculations coupling a proton to a vibrating core [8]), there also exist calculations for Coriolis coupling of a quasi-particle to a rotating core [6,7]). These

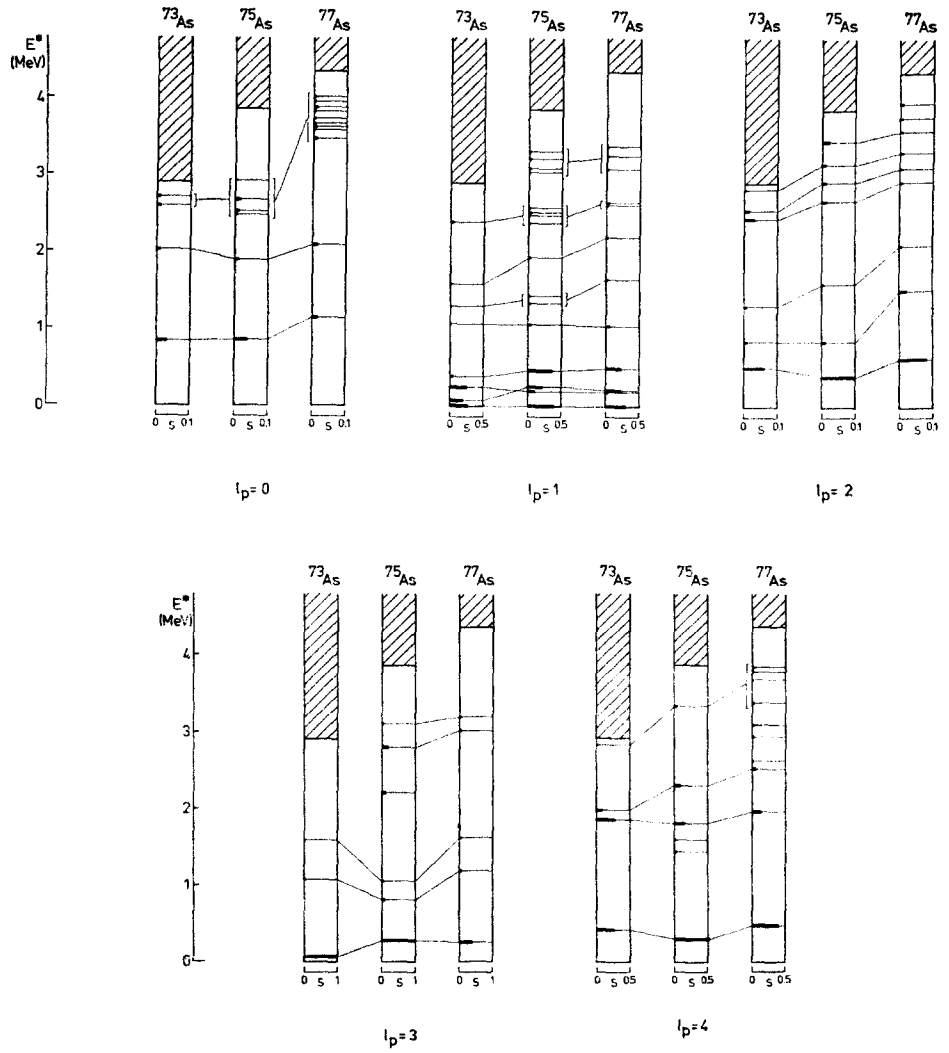

Fig. 11. Comparison of the levels of ^{73,75,77}As found in this investigation sorted according to their l_p values. The thick horizontal bars correspond to the spectroscopic factors.

are also able to reproduce the low-energy As level schemes quite well.

Hartree-Fock-Bogoliubov calculations [25]) yield an increase in deformation and in pairing of the proton states for nuclei towards the end of the f-p shell, which would apply to the Ge target isotopes. In this connection Coriolis-coupling model calculation of Malik and Scholz [6]), including a residual interaction of the pairing type, are of interest. This model yields a strong dependence of positive parity states on the deformation of the nuclei. In particular, the model predicts a low-lying $\frac{5}{2}^+$-$\frac{9}{2}^+$ doublet

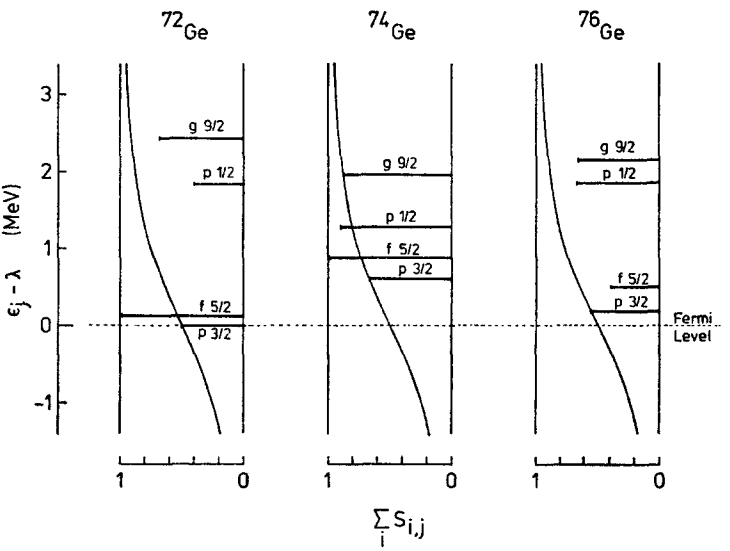

Fig. 12. Expectations of the spectroscopic factors from pairing theory (solid curves) and the summed experimental spectroscopic factors (horizontal bars) at the corresponding single-particle energies obtained in this investigation.

for prolate deformation. The members of this doublet could be found in the odd As isotopes and separated from their neighbours in the Q3D spectra (see tables 2–4). For ^{75}As a prolate deformation with $\beta = +0.10$ is in best agreement with the experimental positive parity levels. For negative parity levels the experiment yields a prolate deformation of $\beta = 0.10$–0.15. With the possible exception of indications of Coriolis-decoupled rotational bands in As isotopes [26]), ^{75}As should be prolate deformed with $\beta = 0.10$–0.15. This is in contradiction to Hartree-Fock-Bogoliubov calculations [25]) which yield oblate shaped nuclei at the end of the f-p shell.

To study the role of the pairing force, needed in the Coriolis-coupling model of Malik and Scholz [6]), a sum-rule analysis was applied to the present results and compared with the pairing theory. The summed spectroscopic factors $\sum_i S_j^i$ represent the vacancies of the shell-model states in a doubly even target nucleus and are given by the Fermi function

$$\sum_i S_j^i = \tfrac{1}{2}\left(1 + \frac{\varepsilon_j - \lambda}{\sqrt{(\varepsilon_j - \lambda)^2 + \Delta^2}}\right),$$

with the single quasiparticle energy $\sqrt{(\varepsilon_j - \lambda)^2 + \Delta^2} = E_j^*$, the energy gap parameter Δ and the chemical potential λ. The solid lines in fig. 12 reproduce the spectroscopic factors for proton states in ^{72,75,77}As expected from this function, using $\Delta = 1.74$ MeV (^{73}As), 1.67 MeV (^{75}As) and 1.59 MeV (^{77}As), as calculated from mass tables [17]). The summed experimental spectroscopic factors are the horizontal bars

in fig. 12. The lengths of the bars correspond to $\sum_i S_j^i(\text{exp})$ and the quasiparticle energies were calculated from

$$\sqrt{(\varepsilon_j-\lambda)^2+\Delta^2} = E_j^*-(E_{\frac{1}{2}^-}-\sqrt{(\varepsilon_{\frac{1}{2}^-}-\lambda)^2+\Delta^2}), \quad E_j^* = \sum_i E_j^i S_j^i / \sum_i S_j^i,$$

normalizing the $p_{\frac{1}{2}}$ state to the theoretical value. This normalization is justified, because it is very probable that all fragments of this lowest orbit have been found at low excitation energies. The experimental values for the $2d_{\frac{5}{2}}$ and $3s_{\frac{1}{2}}$ shells are not given in fig. 12, because their main components are expected at much higher excitation energies than those considered in this investigation.

Fig. 12 shows that only in the nucleus ^{74}Ge are the expected holes from the pairing theory in reasonable agreement with experiment. In ^{72}Ge and ^{74}Ge the $p_{\frac{1}{2}}$ and $g_{\frac{9}{2}}$ orbits seem to be more occupied than predicted from the pairing theory, unless there exist $\frac{1}{2}^-$ and $\frac{9}{2}^+$ levels with large spectroscopic strengths above the investigated energy regions. The empty $f_{\frac{5}{2}}$ proton orbits in ^{72,74}Ge found in this experiment cannot be explained with the simple pairing theory. This discrepancy has its counterpart in $f_{\frac{5}{2}}$ neutron holes in ^{68,70}Zn [ref. [27])] and ^{70,72}Ge [refs. [28,29])]. The occupation of $f_{\frac{5}{2}}$ neutron orbits in these nuclei is underestimated by the pairing theory by a factor of 3–7, while the number of $p_{\frac{1}{2}}$, $p_{\frac{3}{2}}$ and $g_{\frac{9}{2}}$ neutron holes are approximately reproduced [29]).

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