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Study of ^{72}Ge with the ^{71}Ga(^{3}He, d)^{72}Ge reaction

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The ^{71}Ga(^{3}He, d)^{72}Ge reaction has been studied at 25 MeV incident energy with a split-pole spectrometer. The over-all energy resolution was 18 keV. Sixty ^{72}Ge levels, 29 of which observed for the first time, were populated below 5.2 MeV excitation energy. Angular distributions were obtained from 5° to 63° and comparison with distorted-wave–Born-approximation calculations allowed parity assignment and spin limits for 44 levels. Spectroscopic factors are deduced for most of the observed transitions. The whole $2p$-$1f$ and a weak part of the $3s$-$2d$-$1g$ strengths are observed. An interesting result is the strong population of the first excited 0^+ state at 0.690 MeV as compared to the ground state. We present a simple model which can account for this result. Possible $J^{\pi}=0^+$ levels in ^{72}Ge are found at 2.029 and 3.614 MeV.

[NUCLEAR REACTIONS ^{71}Ga(^{3}He, d), $E=25$ MeV; measured $\sigma(\theta)$; ^{72}Ge deduced levels up to 5.2 MeV, J, π, S.]

I. INTRODUCTION

The existence of even nuclei with a $J^{\pi}=0^+$ first excited state is a rare occurrence. Only six such nuclei are known at the present time: ^{16}O, ^{40}Ca, ^{72}Ge, ^{90}Zr, ^{96}Zr, and ^{98}Mo. One can account for low-lying 0^+ states by β vibrations, γ vibrations, pairing vibrations, or shape isomerism. Few calculations exist in the particular case of the even Ge nuclei. Preliminary pairing-plus-quadrupole calculations[1] tried to interpret this 0^+ state by a second minimum in the collective potential energy surface but the excited states were not well reproduced. Stewart and Castel[2] considered the possibility of the coexistence of a vibrator and a rotator to explain the Ge levels. The difficulties in understanding the Ge nuclear structure may arise partly because too little experimental information is available concerning the excited states of the even Ge nuclei.

Recent work[3] using the (p, d) reaction provided information about the neutron structure but many levels populated above 2 MeV appeared, with an energy resolution of 30–40 keV, as unresolved doublets. In order to locate the energy levels, to study the fragmentation of single proton strength, and to follow these properties, as systematically as possible, the (^{3}He, d) reaction was carried out on ^{69,71}Ga and ^{75}As targets. This first paper contains the analysis of the ^{71}Ga(^{3}He, d)^{72}Ge reaction and supersedes preliminary results given previously.[4,5]

II. EXPERIMENTAL PROCEDURE

The ^{71}Ga(^{3}He, d)^{72}Ge experiment was performed with the Orsay MP tandem Van de Graaff accelerator at 25 MeV incident energy. The deuterons were detected using three solid-state position-sensitive detectors in the focal plane of a split-pole magnetic spectrometer. The two outputs E and P from each detector (E proportional to the energy lost by the deuterons, P proportional to this same energy E times a function of the position of the deuterons along the length of the detector) were stored, the ratio P/E computed using an on-line IBM 360 computer, and the result displayed to permit live control of the experiment. The over-all energy resolution was 18 keV full width at half-maximum (FWHM).

Data were taken in 4° steps from 5° to 61° laboratory angle. Two successive exposures at different magnetic fields were necessary at each angle in order to observe the complete energy spectrum (see Fig. 1). For each spectrum a charge of about 3000 μC was accumulated.

The target was prepared by evaporating enriched Ga_2O_3 (99.80%) obtained from the Oak Ridge National Laboratory onto a carbon foil. The possibility of contaminant groups originating from ^{69}Ga was ruled out by direct comparison with our study of the ^{69}Ga(^{3}He, d)^{70}Ge reaction. Absolute cross sections were obtained by comparing the 25 MeV ^{3}He elastic scattering data, measured at 12° and 16°, with the Rutherford cross section and are accurate to about 20%. Angular distribution relative normalizations were obtained from the elastic ^{3}He group observed with a monitor silicon counter mounted at 63° with respect to the beam direction in the scattering chamber.

III. EXPERIMENTAL RESULTS

A. General analysis

Two deuteron spectra (for two successive magnetic fields) recorded at a laboratory angle of 21° are shown in Fig. 1. The numbers on top of each peak refer to nuclear energy levels in ^{72}Ge. The corresponding excitation energies are reported in Table I with an uncertainty of 3 keV except for the weak levels in the upper part of the spectrum where it can reach 5 keV. In the same table are presented the previously known levels reported in the very recent compilation[6] of the Nuclear Data Group; it is clear that many new levels are observed even at low excitation energy, e.g., the levels at 2.029, 2.897, 3.073, and 3.179 MeV. The angular distributions of deuterons are presented in Figs. 2(a), 2(b), and 2(c) according to increasing excitation energies, together with the DWBA predictions. The DWBA analysis was carried out using the program DWUCK.[7] Optical model parameters for deuterons and ^{3}He, taken from Perey and Perey,[8,9] are listed in Table II. The bound-state potential was of the usual Woods-Saxon type, its depth being adjusted in order to reproduce the proton separation energy. Nonlocal and finite-range correction factors were not introduced.

Six states of well known[6] spin and parity ($0^+, 2^+, 4^+$, and 3^-) are observed in ^{72}Ge. As 0^+ and 4^+ states can only be populated by pure $l=1$ and 3 orbital momentum transfers, respectively (if we neglect the $h_{11/2}$ subshell contribution for the last case), they have been used to test the DWBA calculations. If we except a slight difficulty in reproducing the exact amplitude of the first minimum at 17° of the $l=1$ distribution (see the ground-state distribution for instance), the quality of the fit is excellent. This permits us to be confident in the reliability of our analysis in the case of unknown spin levels for which mixed l angular distributions are observed. However, due to more structured distributions and larger relative cross sections, the error on the spectroscopic factors is smaller for $l=1$ than for $l=3$ in the case of an $l=1+3$ admixture. (The same is true for $l=2$ in the case of an $l=2+4$ admixture.)

Spectroscopic factors were extracted using the normalization constant $N=4.42$ given by Bassel[10] and are summarized in Table I.

B. Results analysis

According to the literature,[6] all of the ^{72}Ge levels below 2.5 MeV excitation energy have firm or tentative spin assignments. We shall first present our results for these previously known levels below 2.5 MeV (Sec. B 1); the other levels will be classified and discussed according to the characteristics of their angular distributions (Secs. B 2 to B 6).

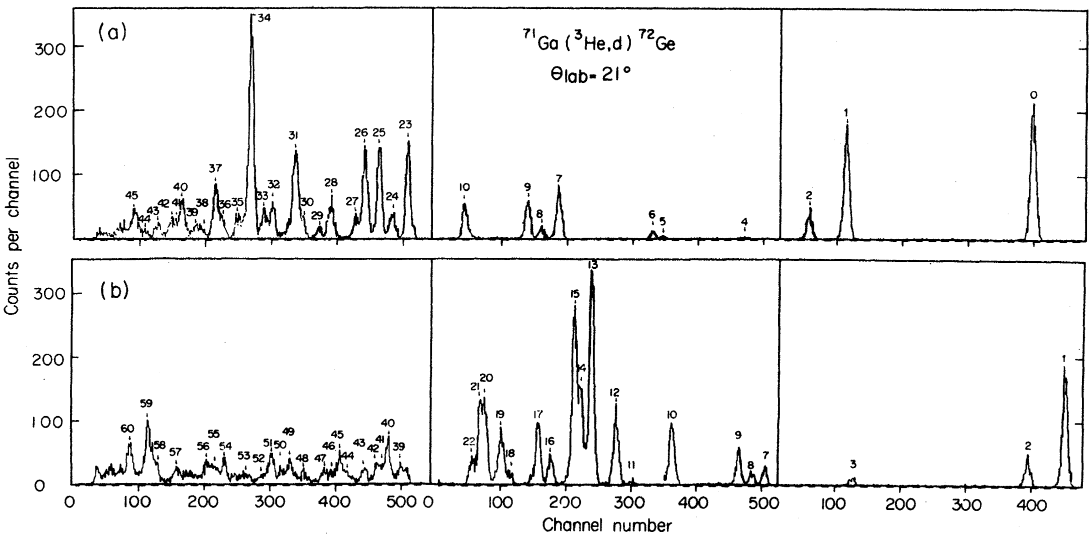

FIG. 1. Deuteron energy spectra from ^{71}Ga(^{3}He, d,)^{72}Ge at 21° lab. The spectra (a) and (b) refer to successive exposures of the three detectors at two different magnetic fields (see text). [NB: Peaks numbers 10 and 7 on the spectra (a) and (b), respectively, have an incorrect intensity due to detector edge effects.]

TABLE I. Levels observed in the reaction ^{71}Ga(^{3}He, d)^{72}Ge at 25 MeV.

	Present work			Literature [a]		$(2J+1)C^2S$ (Present work)				
Level No.	E_x (MeV)	l	J^{π} [b]	E_x (MeV)	J^{π}	$2p_{3/2}$ [c]	$1f_{5/2}$	$1g_{9/2}$	$2d_{5/2}$	$3s_{1/2}$
0	0.0	1	$0^{+}-3^{+}$	0.0	0^{+}	2.50				
1	0.690	1	$0^{+}-3^{+}$	0.691	0^{+}	1.63				
2	0.835	1+3	$1^{+}-3^{+}$	0.834	2^{+}	0.28	0.43			
3	1.465	1(+3)	$0^{+}-3^{+}$	1.464	2^{+}	0.09	<0.04			
4	1.725	3	$1^{+}-5^{+}$	1.728	4^{+}		0.19			
5	2.029	1(+3)	$0^{+}-3^{+}$			0.02	<0.003			
6	2.062	1+3	$1^{+}-3^{+}$	2.065	$(3)^{+}$	0.03	0.28			
7	2.404	1(+3)	$0^{+}-3^{+}$	2.402		0.40	<0.08			
8	2.466	3	$1^{+}-5^{+}$ [d]	2.464	(4^{+})		0.80			
9	2.516	4(+2)	$2^{-}-6^{-}$	2.515	3^{-}			1.90	<0.13	
10	2.754	1+3	$1^{+}-3^{+}$	2.754	$\pi=-$	0.43	0.43			
11	2.897	1(+3)	$0^{+}-3^{+}$			0.03	<0.008			
12	2.949	1+3	$1^{+}-3^{+}$	2.950		0.39	1.56			
13	3.034	1+3	$1^{+}-3^{+}$ [e]	3.036	(2^{-})	1.77	1.77			
14	3.073	3	$1^{+}-5^{+}$ [d]				4.95			
15	3.094	1+3	$1^{+}-3^{+}$	3.094	4^{+}	0.69	3.85			
16	3.179	3	$1^{+}-5^{+}$ [d]				1.32			
17	3.223	1+3	$1^{+}-3^{+}$	3.228	$\pi=-$	0.46	0.58			
18	3.324	1+3	$1^{+}-3^{+}$	3.325	$(3)^{-}$	0.06	0.15			
19	3.357	1+3	$1^{+}-3^{+}$			0.46	0.46			
20	3.422	1+3	$1^{+}-3^{+}$	3.419		0.49	0.51			
21	3.436	1+3	$1^{+}-3^{+}$	3.439		0.07	2.45			
22	3.468	4+2(+0)	$2^{-}-4^{-}$	3.455				0.73	0.08	<0.02
23	3.506	1+3	$1^{+}-3^{+}$			0.50	1.15			
24	3.565	1+3 4+2(+0)	$(1^{+}-3^{+})$ $(2^{-}-4^{-})$	3.566		(0.02)	(1.15)	(0.44)	(0.12)	(0.04)
25	3.614	1(+3)	$0^{+}-3^{+}$	3.619		0.82	<0.17			
26	3.662	1+3	$1^{+}-3^{+}$	3.667		0.62	0.63			
27	3.691	1+3	$1^{+}-3^{+}$			0.16	0.09			
28	3.777	1+3	$1^{+}-3^{+}$			0.25	0.57			
29	3.815	4+2(+0)	$2^{-}-4^{-}$	3.816				0.46	0.02	<0.01
30	3.867			3.872						
31	3.895	1+3	$1^{+}-3^{+}$	3.890	$\pi=-$	0.42	1.80			
32	3.975	1+3 4+2(+0)	$(1^{+}-3^{+})$ $(2^{-}-4^{-})$	3.965	$\pi=-$	(0.04)	(0.72)	0.49	0.12	<0.05
33	4.002	1+3	$1^{+}-3^{+}$	3.995		0.18	0.41			
34	4.047	1+3	$1^{+}-3^{+}$ [e]	4.041		1.41	1.74			
35	4.092	1+3	$1^{+}-3^{+}$	4.090		0.17	0.12			
36	4.147	1+3	$1^{+}-3^{+}$			0.14	0.12			
37	4.171	1+3	$1^{+}-3^{+}$			0.37	0.68			
38	4.224	2+4	$2^{-}-4^{-}$					0.48	0.12	
39	4.245	3(+1)	$1^{+}-5^{+}$			<0.02	0.60			
40	4.290	1+3	$1^{+}-3^{+}$			0.25	0.84			
41	4.315	1+3	$1^{+}-3^{+}$			0.33	0.12			
42	4.330	1+3 4+2(+0)	$1^{+}-3^{+}$ $2^{-}-4^{-}$	4.339		(0.04)	(0.73)	(0.24)	(0.07)	(0.03)
43	4.374	1+3	$1^{+}-3^{+}$			0.06	0.50			
44	4.419	(1+3)	$(1^{+}-3^{+})$							
45	4.453	4+2+0	2^{-}	4.458	$\pi=-$			2.38 [f]	0.05	0.01
46	4.483	1+3 4+2+0	$(1^{+}-3^{+})$ $(2^{-}-4^{-})$							
47	4.512	4+2+0	2^{-}					0.64 [f]	0.04	0.01
48	4.575	(1+3)								

TABLE I *(Continued)*

Level No.	Present work E_x (MeV)	l	J^{π} [b]	Literature [a] E_x (MeV)	J^{π}	$(2J+1)C^2S$ (Present work) $2p_{3/2}$ [c]	$1f_{5/2}$	$1g_{9/2}$	$2d_{5/2}$	$3s_{1/2}$
49	4.620	1+3	1^+-3^+			0.12	0.29			
50	4.650	4+2	2^--4^-					0.46	0.05	
51	4.679	4+2	2^--4^-					1.14	0.06	
52	4.705									
53	4.755	4+2(+0)	2^--4^-					0.43	0.05	<0.02
54	4.840	1+3	1^+-3^+			0.08	0.20			
55	4.875	(1+3)	(1^+-3^+)							
56	4.903									
57	5.004									
58	5.076	4+2+0	2^-					1.23 [f]	0.02	0.02
59	5.100	4+2(+0)	2^--4^-					1.70	0.09	<0.02
60	5.160	4+2(+0)	2^--4^-					1.26	0.07	<0.02

[a] Reference 6 (the levels not observed in the present work are not reported).

[b] Underlined values refer to most probable assignments (see text).

[c] If $2p_{1/2}$ transfer is assumed, one can find $S_{1/2} \sim 1.17 S_{3/2}$.

[d] $J^{\pi}=4^+$ or 5^+ is the most probable assignment (see text).

[e] $J^{\pi}=1^+$ or 2^+ is the most probable assignment (see text).

[f] Spectroscopic factor calculated assuming $g_{7/2}$ transfer (see text).

1. *Known levels below 2.5 MeV*

The ground state (0_1^+) and first excited state (0_2^+) transitions are very well reproduced by $l=1$ calculations, the spectroscopic factor of the 0_2^+ level being 65% of the ground state one. The two 2_1^+ and 2_2^+ states, at 0.835 and 1.465 MeV, respectively, are populated by $l=1+3$ transitions, the second having a smaller relative $f_{5/2}$ component and being more weakly excited.

The following level at 1.725 MeV has a very low cross section (10 μb/sr) but the absence of any background in that region of the spectrum allows us to propose a pure $l=3$ transition in good agreement with the previous $J^{\pi}=4^+$ assignment.

The spin-parity assignments $J^{\pi}=1^+-3^+$ are established for the 2.062 MeV level in agreement with the tentative[6] value $J^{\pi}=(3)^+$. A pure $l=3$ transition is observed for the 2.466 MeV level previously known[6] as $J^{\pi}=(4^+)$. The known $J^{\pi}=3^-$ level at 2.516 MeV is populated by an $l=4$ transition which carries a large part of the $g_{9/2}$ strength, and possibly a very weak $l=2$ component. No evidence is found here for the 2.505 and 2.583 MeV levels indicated in earlier investigations.[3,11]

2. *l=1 angular distributions*

Besides the ground and 0.690 MeV levels, four other levels at 2.029, 2.404, 2.897, and 3.614 MeV are populated by an $l=1$ transfer (i.e., the fit is good for a pure $l=1$ calculation but a weak $l=3$ component may exist with relative strength smaller than 0.2). Selection rules permit spin and parity $J^{\pi}=0^+-3^+$; it is only among these levels that a 0^+ state could have been observed in this experiment.

The 2.029 MeV level is weakly excited and seems to be observed for the first time. A level at 2.043 MeV apparently distinct from the known level at 2.065 MeV was observed by Curtis, Lutz, and Bartolini[14] in a ^{70}Ge(p,p') experiment with 70 keV resolution but no definitive statement about its spin could be made. The literature[6] generally con-

TABLE II. Optical and bound-state potential parameters used in the DWBA analysis.

Particle	V (MeV)	r (fm)	a (fm)	W (MeV)	r_w (fm)	a_w (fm)	$4W_D$ (MeV)	r_D (fm)	a_D (fm)	r_c (fm)	λ
^{3}He [a]	−173.8	1.15	0.733	−22.63	1.55	0.856				1.40	
d [b]	−81.6	1.234	0.776				93.96	1.404	0.559	1.40	
p	c	1.25	0.65							1.40	25

[a] Reference 9.

[b] Reference 8.

[c] Adjusted to give the correct separation energy.

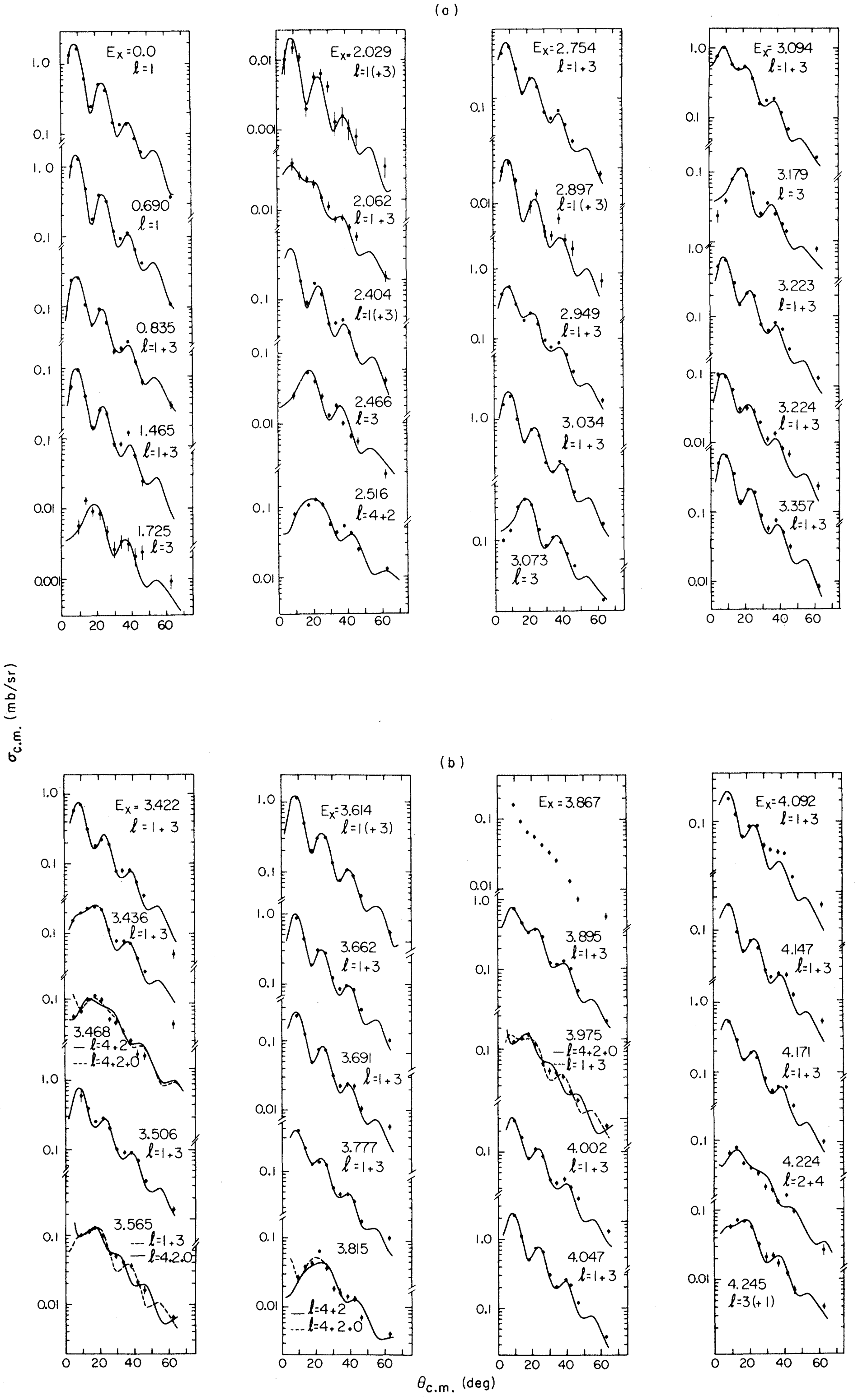

FIG. 2. (a)–(c) Angular distributions of the ^{71}Ga(^{3}He, d)^{72}Ge reaction. Vertical bars are the statistical errors. Curves are DWBA predictions assuming the indicated l values.

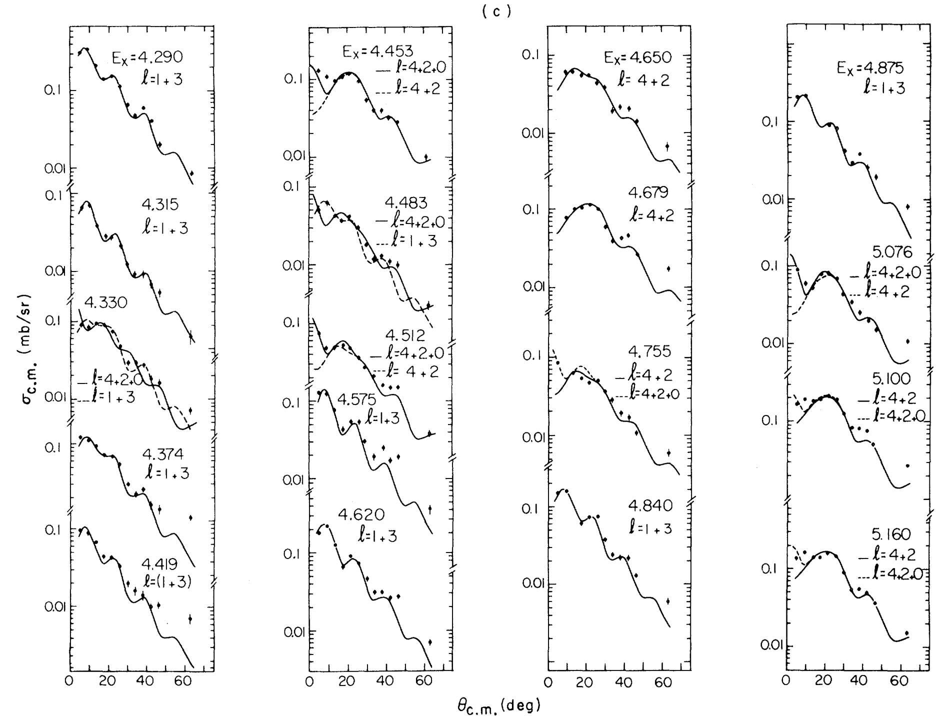

FIG. 2 (*Continued*)

siders a unique level at 2.065 MeV. The 2.029 MeV level is an attractive candidate for a second $J^\pi = 0^+$ excited state. This proposition is supported by the following considerations: if such a 0_3^+ level exists at 2.029 MeV, it should decay primarily to a lower 2^+ level (at 0.835 or 1.465 MeV) yielding 1.194 or 0.564 MeV γ rays. A 1193.6 keV γ ray was observed but not assigned to a particular transition in the decay scheme of ^{72}Ge by Camp.[13] More recently, Rester *et al.*[11,12] investigated the ^{72}Ga and ^{72}As decays and observed a 1193.9 keV γ transition tentatively assigned to the deexcitation of a "new" level at 3.707 MeV, not confirmed however by other experiment or information. This transition might be the 2.029-0.835 MeV cascade.

The $J^\pi = 0^+$ possibility is ruled out for the 2.404 MeV level by the observation[11,12] of γ transitions from this level to the first two 0^+ levels in ^{72}Ge.

The 2.897 MeV level was previously unknown but indication for this level can perhaps be found in the experiments of Rester *et al.*[11,12] and Camp[13] where nonassigned 2.897 and 0.175 MeV γ rays are observed which may correspond to the 2.897 → ground-state and 3.073 → 2.897 MeV γ transitions, respectively. If this were true, the 0^+ value of our $J^\pi = 0^+-3^+$ assignments could be eliminated.

An $l=1$ transferred momentum is found for the 3.614 MeV level (previously observed in the ^{72}As and ^{72}Ga decays[13]) leading to $J^\pi = 0^+-3^+$ assignments.

3. *l=3 angular distributions*

Two $l=3$ transitions are found for the levels at 3.073 and 3.179 MeV carrying an important part of the observed $f_{5/2}$ strength. These two levels are observed for the first time.

The deduced assignments are $J^\pi = 1^+-5^+$. No $l=1$ component being observed, we propose $J^\pi = 4^+-5^+$ as tentative values for these two levels.

4. *Unambiguous l=1+3 angular distributions*

The angular distributions for 25 levels above 2.5 MeV are fitted by mixed $l=1+3$ DWBA calculations. Among them, the levels at 3.357, 3.506, 3.691, 3.777, 4.147, 4.290, 4.315, 4.374, 4.620, and 4.840 MeV were previously unknown. The selection rule limits are $J^\pi = 1^+-3^+$.

For the four levels at 2.754, 3.034, 3.223, and 3.895 MeV, the $J^\pi = 1^+-3^+$ assignments deduced from the unambiguous $l=1+3$ patterns are in disagreement with previous assignments[6] and particularly with the (p,d) data[3] where a negative parity is proposed. Concerning the 2.754, 3.034, and 3.895 MeV levels, it seems that the 40 keV resolution of the (p,d) experiment could be responsible for these discrepancies: The presence of the second excited state of ^{75}Ge as an impurity in the vicinity of the 2.754 MeV level and of the 3.073 and 3.872 MeV levels of ^{72}Ge as possible contaminant groups for the 3.034 and 3.895 MeV levels, respectively, may explain the absence of good fits in the (p, d) data.[3] The discrepancy remains unexplained for the 3.223 MeV level except for the possibility of a doublet at this energy.

5. $l=2+4$ *angular distributions*

Levels at 3.468, 3.815, 4.224, 4.650, 4.679, 4.755, 5.100, and 5.160 MeV are found to be populated by $l=4+2$ transitions (with a possible weak $3s_{1/2}$ component for some of them). This leads to $J^\pi=2^- - 4^-$ assignments. Nevertheless, the presence of an $l=0$ ($3s_{1/2}$) admixture in $l=4+2$ transitions is plausible for the 4.453, 4.512, and 5.076 MeV transitions. This would lead to $J^\pi=2^-$ for these levels and would mean that we observe $g_{7/2}$ transitions in our experiment. The negative parity for the level at 4.453 MeV is in agreement with the (p, d) data.[3]

6. *Ambiguous distributions*

For four of the remaining levels, it is not possible to make a choice between $l=1+3$ (with about 95% of $l=3$) and $l=4+2(+0)$ with about 20% $l=2$ admixture, this being mainly due to too closely spaced levels and consequent doubtful separation. These levels, indicated in Table I, cannot receive J^π assignments from our data. However, among the levels previously reported[6,3] between 3.950 and 4.000 MeV, we can propose a correspondence between our 3975 ± 5 keV level and the 3965 ± 10 keV ($\pi=-$) level. Then, our $l=4+2$ fit leads to the $J^\pi=2^- - 4^-$ possibility.

C. Discussion

On the basis of the apparent absence of an $l=3$ component in the angular distributions of the 2.029, 2.404, 2.897, and 3.614 MeV levels, we can say that a new 0^+ level could only be observed in this experiment among these four levels. We have shown however, that previously observed (or possible) γ transitions to known 0^+ levels ruled out the 0^+ assignment for the 2.404 (and perhaps the 2.897 MeV level too). The 2.029 and 3.614 MeV levels remain as possible 0^+ states. This is to be compared with other Ge isotopes where more than one 0^+ excited state is known.

The distribution of the observed spectroscopic factors is shown in Fig. 3. The observed strengths $G_{lj}=\sum_i(2J_i+1)\,(2J_0+1)^{-1}C^2S^i_{lj}$ ($J_0=\frac{3}{2}$ being the ^{71}Ga ground-state spin) are given in Table III.

It is clear that the strength for the $1g_{7/2}$, $2d_{5/2}$, and $3s_{1/2}$ orbitals is far from being exhausted. The observed $g_{9/2}$ strength seems to be highly fragmented between levels lying mostly above 3.5 MeV. Moreover, only 30% of the sum-rule limit is observed up to 5.2 MeV in our experiment. This situation differs from what is observed in the Zn(^{3}He, d)Ga reactions[15,16] where the observed $g_{9/2}$ strength (about 30–50% of the sum-rule limit) is concentrated around 2 MeV excitation energy.

A very simple model can account for the measured values of the spectroscopic factors of the two 0^+ states at 0.0 and 0.690 MeV. Let us take for the ground state of the target a wave function:

$$\psi_{\mathrm{Ga}}=\alpha(p_{3/2})^3{}_{3/2}+\beta(f_{5/2})^2{}_0 p_{3/2} \tag{1}$$

and for the 0^+ states, orthogonal wave functions:

$$\psi_{0_1^+}=\alpha'(p_{3/2})^4{}_0+\beta'(f_{5/2})^2{}_0(p_{3/2})^2{}_0, \tag{2}$$

$$\psi_{0_2^+}=\beta'(p_{3/2})^4{}_0-\alpha'(f_{5/2})^2{}_0(p_{3/2})^2{}_0. \tag{3}$$

If we admit a pure $(p_{3/2})^3$ configuration for the

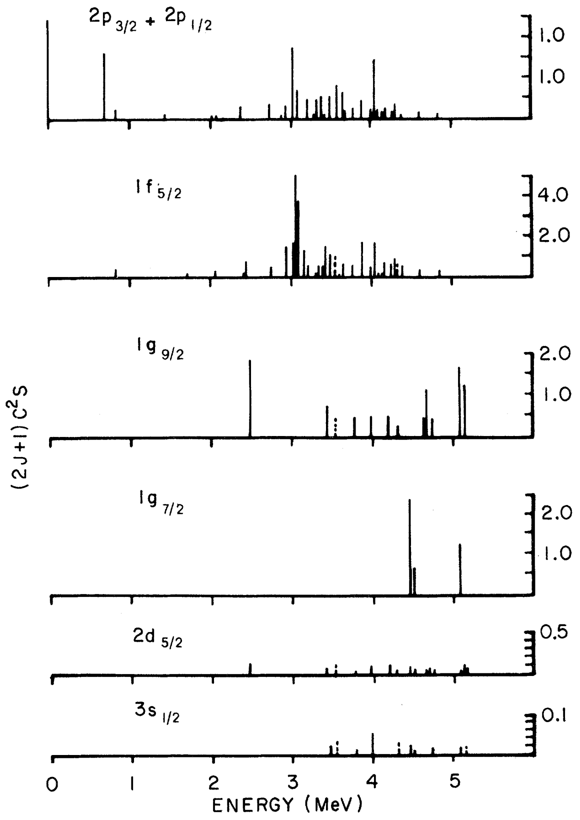

FIG. 3. Spectroscopic strengths distribution obtained in the present study. The $(2J+1)$ C^2S values for each l transition are represented by the length of the vertical bars.

TABLE III. Summed strengths: $\sum_i (2J_i+1)(2J_0+1)^{-1}C^2S_i$ for levels in ^{72}Ge up to 5.2 MeV excitation.

	$2p$	$1f_{5/2}$	$2p+1f$	$1g_{9/2}$	$1g_{7/2}$	$2d_{5/2}$	$3s_{1/2}$	$1f_{7/2}$
This work [a]	3.90	7.40	11.30	2.40 (2.90) [b]	1.06	0.23	0.05	
^{70}Zn(^{3}He, d)^{71}Ga [c]	4.58	5	9.58	2.9–3.6		1.01	0.29	
^{68}Zn(^{3}He, d)^{69}Ga [c]	3.84	6.53	10.37	4.90		0.68	0.21	0.65
Sum-rule limit for Ga target	3	6	9	10	8	6	2	

[a] Uncertain spectroscopic factors (given in a parentheses in Table I) are not included.

[b] Intensity obtained if one does not distinguish between the $1g_{9/2}$ and $1g_{7/2}$ orbitals.

[c] Reference 15.

target ground state ($\alpha=1$), we get (with $\alpha'^2=0.6$):

$$C^2S_{0_1^+}=2.4 \text{ and } C^2S_{0_2^+}=1.6$$

in very good agreement with the experimental values in Table I. Then, the whole $p_{3/2}$ strength is exhausted in the two 0^+ states.

In fact, it seems that our experimental values may be slightly overestimated if we compare the summed $f+p$ strength of 11.3 to the sum-rule value of 9 (three particles in the $f-p$ shell in the target). The 20% renormalization needed is within the experimental uncertainty in determining the absolute values, not taking into account the DWBA uncertainties. The renormalized values will be used in the following discussion.

A value of $\alpha^2=0.8$ would give the best over-all agreement with our renormalized data. The ratio of the two spectroscopic factors for the two 0^+ states is compatible with two sets of numerical solutions: $\alpha'=\sqrt{0.88}$ ($\beta'=-\sqrt{0.12}$) and $\alpha'=\sqrt{0.28}$ ($\beta'=+\sqrt{0.72}$). The deduced spectroscopic factors (see Table IV) are in acceptable agreement with experiment. They exhaust about 64% of the $p_{3/2}$ strength. As the two known 2^+ states at 0.835 and 1.465 MeV exhaust in our data 5.5%, about 30% of the $p_{3/2}$ strength is therefore still to be exactly located in one or several 2^+ states with the chosen value of α^2. The total $p_{3/2}$ strength $G_{l,j}=G_{1,3/2}$ for the proposed target wave function is 1.4. The difference between the renormalized experimental value $G_{1(3/2+1/2)}=3.1$ and this value is equal to 1.7 which, corrected for the fact that $S_{1/2}\sim 1.17S_{3/2}$, gives an experimental $G_{1,1/2}$ value of 1.99 very close to the theoretical one $G_{1,1/2}=2$. The agreement is good also for the strength $G_{3,5/2}$ (see Table IV).

In summary, the experimental results do not disagree with the very simple model proposed, with a percentage of $(f_{5/2})^2{}_0p_{3/2}$ admixture in the target ground state less than or equal to 20%. This model gives a very simple explanation, very similar to the one given[17] for ^{90}Zr, of the structure of the low-lying 0^+ state. Due to the orthogonality of the proton wave functions, it can account also for the very weak cross section recently observed[3] in the ^{73}Ge(p, d)^{72}Ge reaction for the 0_2^+ state.

In the framework of this model, most of the levels populated by $l=1$ transitions, particularly above 3 MeV, correspond to a $2p_{1/2}$ transfer, their spin and parity assignments being therefore $J^\pi=1^+, 2^+$. As it appears however impossible to make a firm distinction, all the $l=1$ spectroscopic factors presented in Table I are calculated assuming a $2p_{3/2}$ transfer. (For $2p_{1/2}$ transfer, one can apply $S_{1/2}\sim 1.17S_{3/2}$.) The assignment of $p_{1/2}$ transfer (and $J^\pi=1^+-2^+$) can however be considered as unambiguous for the strongly excited levels at 3.034 and 4.047 MeV.

IV. CONCLUSIONS

The proton configuration states in ^{71}Ga and ^{72}Ge have been investigated using the ^{71}Ga(^{3}He, d)^{72}Ge reaction. Twenty-nine new levels of ^{72}Ge are observed and 44 new spin-parity assignments or limits are proposed. Most of the previously known levels were deduced from γ-ray measurements in β-decay study and are confirmed by our work.

We emphasize the observation of possible new 0^+ states at 2.029 and 3.614 (and perhaps 2.897) MeV, 4^+-5^+ states at 3.073 and 3.179 MeV, and

TABLE IV. Comparison of some experimental spectroscopic factors C^2S and strengths $G_{l,j}$ with our model calculations.

	$C^2S_{0_1^+}$	$C^2S_{0_2^+}$	$G_{1,1/2}$	$G_{3,5/2}$
Renormalized experimental values	2.0	1.30	1.99	5.92
Model values	2.25	1.48	2.0	5.6

1^+-2^+ states at 3.034 and 4.047 MeV. It has been shown that a very simple model can be used to account for the observed strong $l=1$ transitions to the first two 0^+ states, which exhaust at least about 65% of the $p_{3/2}$ strength. Our results indicate the possibility of up to a 20% admixture of the $(f_{5/2})^2{}_0 p_{3/2}$ configuration in the ^{71}Ga ground state.

The analysis shows that the $1g_{9/2}$, $2d_{5/2}$, and $3s_{1/2}$ (and perhaps $1g_{7/2}$) proton subshells are starting to fill in ^{72}Ge. A shell-model calculation in this region should include $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, and $1g_{9/2}$ configurations and seems impracticable at the present time.

A forthcoming paper will present the ^{69}Ga(^{3}He, d)^{70}Ge and ^{75}As(^{3}He, d)^{76}Se results and a more detailed analysis of the results in the framework of different models.

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