$^{70,72,74,76}Ge(d,^3He)^{69,71,73,75}Ga$

réactions at 26 MeV

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Abstract

The ^{70,72,74,76}Ge(d,^{3}He)^{69,71,73,75}Ga reactions have been studied at 26 MeV with 15 keV resolution (F.W.H.M), using the Orsay MP tandem accelerator and a split pole magnetic spectrometer. The spectroscopic factors are determined for 15 levels in ^{69}Ga and 11 levels in each of the 3 other Ga isotopes. Level schemes are proposed for the practically unknown ^{73}Ga and ^{75}Ga. Very simple model wave functions previously proposed for Ge nuclei are seen to reproduce quite well the measured occupation numbers for the proton orbitals. Anomalies in these occupation numbers are observed between $Z = 31$ and 32 and between $N = 40$ and 42, this last one corresponding to the structural transition observed recently in a comparison of the (p,t) and (t,p) reactions. These anomalies could be related to changes in the nuclear shape.

I. Introduction

The structure of the nuclei in the region of neutron number N = 40 is still a subject of controversy. The occurence of a low-lying 0^+ excited state in the even-even nuclei is interpreted either in terms of neutron configuration mixing in the 2p1/2, 1g9/2 orbitals[1)] or in terms of proton configuration mixing in the 2p3/2, 1f5/2 orbitals[2,3)] or even in terms of shape coexistence[4)]. Some discontinuities observed at N = 40 in systematic studies of even-even nuclei in this region by means of $(^3He,d)$[2)], $(d,^3He)$[5)], (p,t)[6)] and (t,p)[7)] reactions, appear as an evidence for a structural transition between the N=40 and N=42 ground states. The primary aim of the present work is to test the possible influence of this transition on the occupation numbers of the proton shell model orbitals in the ground states of the even-even Ge isotopes. These occupation numbers could in principle be deduced from the number of holes measured[8)] as the sum of the spectroscopic factors in the $Ge(^3He,d)As$ reactions. However the number of protons being appreciably smaller than the number of proton holes in the valence shells (2p, 1f5/2), a direct measurement by means of the $Ge(d,^3He)Ga$ reaction is expected to give more reliable values. In the case of the reaction on the two lightest Ge isotopes, the spin and parity of the levels of the final Ga nuclei are well known and there is no difficulty to distribute the l = 1 strength between 2p1/2 and 2p3/2 and the l=3 strength between 1f5/2 and 1f7/2. The two heaviest Ga isotopes, ^{73}Ga and ^{75}Ga, are however practically unknown and the second aim of this work is to obtain spectroscopic informations on these nuclei.

2. Experimental procedure

The Orsay MP tandem Van de Graaff accelerator was used to provide a 1μA beam of 26 MeV deuterons on GeO_2 targets. The thicknesses and isotopic enrichments of these targets are given in table 1. A split pole magnetic spectrometer equiped with four solid state position sensitive detectors (50 mm long) in its focal plane was used for analysis and detection of the emitted ^3He particles. The experimental set-up described in previous papers[2,5,6)] has been improved by the installation of remotely operated, quickly removable beam defining slits, at the entrance of the reaction chamber. This improvement was necessary at forward angles to avoid edge scattering of deuterons during the experiment, the magnetic rigidity of the deuterons of the beam being larger than that of the detected ^{3}He particles. It was possible in this way to measure the cross sections at angles as small as 8°.

Typical spectra are given in figure 1. The overall resolution is 15 keV (F.W.H.M). Comparison of spectra permits the identification of contaminant groups originating from the other isotopes. The absolute cross sections are estimated with an uncertainty of the order of 20%, mainly due to the uncertainty in the determination of the target thicknesses (using du α gauge). A relative normalization of the cross sections on different isotopes was obtained using a natural Ge target.

3. Analysis of the data.

3.1. Excitation energies and Q values.

The presence on the same spectra of groups of ^{3}He originating from different isotopes permits the measurement of the difference of Q values with an accuracy estimated to lie between ± 7 keV. Table 2 shows that the measured Q values are in agreement with those reported by H. Wapstra and K. Bos$^{9)}$ and improve the accuracy of the known Q values for the heaviest isotopes. The accuracy of the measured excitation energies is also estimated to be within ± 7 keV.

3.2. D.W.B.A. analysis, choice of the optical potentials.

The angular distributions are shown in figures 2 to 5. D.W.B.A. calculations were carried out using the program DWUCK$^{10)}$. Optical model parameters previously used for the analysis of the (^{3}He,d) reaction in the Ge-Ga region$^{2;8,11)}$ fail to fit consistently the whole set of experimental results : The Q value varies from isotope to isotope and the kinetic energy of the outgoing ^{3}He particles approaches the coulomb barrier for the heaviest isotopes. There is then a dependance of the angular distribution on the isotope and on the excitation energy. The dependance on the isotope is larger in the calculated angular distributions than in the experimental ones. For instance the potentials which gave good fits for the ^{69,71}Ga(^{3}He,d)^{70,72}Ge reactions$^{2)}$ give also good fits for the inverse ^{70,72}Ge(d,^{3}He)^{69,71}Ga reactions, but poorer fits for the reactions on the heaviest Ge isotopes. The potential from Bechetti and Greenlees[12), for ^{3}He contains a (N-Z)/A dependant term and gives, associated with the potential from Perey and Perey[13) for deuterons (see table 3), a rather good fit for the whole set of experimental results. All the spectroscopic factors given in tables 4 to 7 have been extracted using these potentials. (The potentials of ref.2 give about the same results for ^{69,71}Ga).

4. Spectroscopic results for the Ga isotopes.

The spectroscopic results deduced from the DWBA analysis are presented in tables 4 to 7. The transfered angular momentum 1 and the spectroscopic factor C^2S_{1j} have been determined for 15 levels in ^{69}Ga, 11 levels in ^{71}Ga, 11 levels in ^{73}Ga and 11 levels in ^{75}Ga. The excitation energy, spin and parity were previously known for most of the levels observed in ^{69}Ga 14) and ^{71}Ga 15). The spectroscopic factors are practically the only new information obtained. However the 1 = 3 pattern of the angular distributions corresponding to the 2425 keV level in ^{69}Ga and to the 1907 and 1995 keV levels in ^{71}Ga limits the previously unknown spin and parity value to $J^\pi = 5/2^-$ or $7/2^-$. The value $J^\pi = 7/2^-$ is prefered because :

i) The total 2p,1f5/2 spectroscopic sum rule limit is already reached with the sum of the spectroscopic factors for levels known as $J^\pi = 1/2^-, 3/2^-$ and $5/2^-$. Levels of unknown spin, with large 1 = 3 spectroscopic factors, as is the case for the levels discussed, should therefore have the spin-parity value $J^\pi=7/2^-$.

ii) These levels have not been observed in the ^{68,70}Zn(^{3}He,d)^{69,71}Ga reactions[11). That can be explained easily if $J^\pi=7/2^-$ because the f7/2 proton orbital is essentially full in the Zn ground states. (Which is not the case for the f5/2 orbital).

The value $J^\pi = 7/2^-$ is also prefered, for the same reasons, for the 1396 keV level of ^{71}Ga, already known as $J^\pi=5/2^-$ or $7/2^-$. The arguments are weaker for the 1476 keV level of ^{71}Ga, because the spectroscopic factor is smaller.

The two heaviest Ga isotopes studied were, until very recently, practically unknown. For ^{73}Ga, Three γ rays were observed$^{16)}$ in the ^{73}Zn $\rightarrow$ ^{73}Ga beta decay. Other informations have been deduced $^{7)}$ from the shapes of the angular distributions in the ^{71}Ga(t,p)^{73}Ga reaction. Levels with L = 0 pattern in the (t,p) reaction have necessarily the same spin and parity, $J^{\pi}=3/2^{-}$, as the ^{71}Ga ground state. This is the case for the ground state and the levels at 214 and 912 keV. The level at 1112 keV is the only one corresponding to an 1 = 1 transfer in the (d,^{3}He) reaction (which limits the spin-parity value to $J^{\pi} = 1/2^{-}$ or $3/2^{-}$) and to a transfer L $\neq$ 0 in the (t,p) reaction. Accordingly the value $J^{\pi}=1/2^{-}$ is prefered, but $3/2^{-}$ cannot be completely excluded. We have no way to make a choice between $J^{\pi}=5/2^{-}$ or $7/2^{-}$ for the low-lying levels at 198 and 495 keV populated by 1=3 transfer. The value $J^{\pi}=5/2^{-}$ is prefered from a comparison with the level schemes of the ligther Ga isotopes (see figure 6). This argument could seem weak, but it is buttressed by the fact that the strength of the two 1=3 transitions corresponding to these levels adds nicely to the measured 1=1 strength to give a value of 4.07, very close to the sum rule limit of 4 for the 2p,1f5/2 valence shells. Other higher lying levels with large spectroscopic factors, corresponding to 1=3 transfer, are supposed to have $J^{\pi}=7/2^{-}$.

Excitation energies for 3 levels of ^{75}Ga have been deduced by Aleklett et al$^{17)}$ from the γ rays observed in the ^{75}Zn$\rightarrow$^{75}Ga beta decay. Their 228 keV level corresponds to the second excited level of ^{75}Ga, observed in the (d,^{3}He) reaction at 232 keV. The region where the proposed 432 and 606 keV levels of ^{75}Ga should appear is obscured at forward angles in the ^{76}Ge(d,^{3}He)^{75}Ga reaction by the very intense peak of the ^{16}O(d,^{3}He)^{15}N$_{g.s}$ reaction. Very weak peaks, possibly corresponding to these levels, are observed at other angles, but only upper limits for the spectroscopic factors can be given. The spin value is not determined for any level in our study, only the momentum transfer 1 is determined, hence the spin-parity values are $J^{\pi}=1/2^{-}$ or $3/2^{-}$ for 1=1 transfer, $J^{\pi}=5/2^{-}$ or $7/2^{-}$ for 1=3 transfer. Hypothesis are made, based on a comparison with the level schemes of the lighter Ga isotopes and continuity arguments : the ground state is supposed to have $J^{\pi}=3/2^{-}$ as the ground states of all the other Ga isotopes, the first level at 232 keV corresponding to an 1=3 transfer is supposed, as in the other Ga isotopes to have $J^{\pi}=5/2^{-}$. The other levels, at higher excitation energies, with large spectroscopic factors corresponding to 1=3 transfer, are supposed to have $J^{\pi}=7/2^{-}$. The level at

1236 keV, which has an 1=1 spectroscopic factor of the same order as the one measured for the $J^{\pi}=1/2^-$ level around 1100 keV excitation energy in ^{71}Ga and ^{73}Ga, is tentatively supposed to have $J^{\pi}=1/2^-$.

The summed spectroscopic strengths, energy weighted spectroscopic strengths and percentage of the observed total strength carried by the strongest transition, for each 1,j value, are given in table 8. It can be seen that the major part of the observed 2p1/2, 2p3/2, 1f5/2 and 1g9/2 strenght is carried by a single level in each of the isotopes studied. The same is true in the ^{64,70}Zn(^{3}He,d)^{65,71}Ga reactions[11)] and the strength is carried by the same levels in ^{69,71}Ga, observed in both studies. These levels, which have therefore a strong single particle character are : the $J^{\pi}=3/2^-$ ground state, a $J^{\pi}=1/2^-$ level lying under 350 keV in ^{65,67,69}Ga and raising between 1100 and 1240 keV in ^{71,73,75}Ga, the first $J^{\pi}=5/2^-$ level, whose energy varies between 180 and 580 keV with a maximum energy in ^{69}Ga, a $J^{\pi}=9/2^+$ level whose energy is minimum near 1200 keV for ^{73}Ga. (It must be stressed that the 1=4 nature of the transitions observed for ^{73,75}Ga is only tentative). Correspondance between these levels are indicated in figure 6 where the level schemes of all the Ga isotopes between A=65 and A=75 are compared.

5. Occupation numbers in the ground states of Ge and neighbouring nuclei.

5.1. Empirical discussion.

As shown by Mac Farlane and French[18)] the sum of all the spectroscopic factors corresponding to a given 1,j transfer in a pick-up reaction is equal to the average number of particles on the shell model 1,j orbital in the target ground state wave function. The summed spectroscopic factors shown in table 8 permit to conclude that :

i) Only a weak ($C^2S \approx 0.25$) 1=4 transition is observed. This result, as well as the fact that in the Ge(^{3}He,d) As only a weak 1=3 strength corresponding to $J^{\pi}=7/2^-$ has been observed[8)] indicates that, to a good approximation, the 2p,1f5/2 orbitals may be considered as the only active ones in the proton wave functions of the Ge ground states.

ii) The total 2p,1f5/2 strength is very close to 4, indicating that essentially all the strength is observed.

iii) Only a part of the possible 1f7/2 strength is observed, clearly because of the limitation in excitation energy of the observed spectra. The fact that a larger fraction is observed in the two heaviest isotopes seems to indicate that the 1f7/2 orbital is coming closer to the Fermi surface than in the lighter isotopes.

iiii) There is a striking change between the wave functions of the two lightest and of the two heaviest Ge isotopes : there is one more proton on the f5/2 orbital and one less on the 2p3/2 orbital in the two heaviest isotopes (N=42 and 44) than in the two lightest (N=38 and 40). This clearly corresponds to an abrupt change in the proton configurations between N=40 and 42.

An anomaly of the occupation numbers for several nuclei in the same region has been previously reported[5)] : the population of the proton p orbitals, also measured using the (d,^{3}He) reaction, is larger in the Ga isotopes (Z=31) than in ^{75}As (Z=33). The comparison, in table 9, of the present ^{70,72,74,76}Ge(d,^{3}He)^{69,71,73,75}Ga results with the previous ^{69,71}Ga(d,^{3}He)^{68,70}Zn and ^{75}As(d,^{3}He)^{74}Ge results indicates that the previously reported anomaly is in fact due to the transition between N=40 and N=42, rather than to the change in the number of protons when going from Ga to As.

In summary, one can say schematically that, when one adds protons to a given nucleus, at least between Z=31 and 33, they never go on the p orbitals but on the f5/2 orbital.

It is possible to deduce, from a study of the (d,^{3}He) reaction[19)] on the Cu isotopes, that in these nuclei the number of protons on the p orbitals lies between 0.9 and 1.We do not have precise numbers for the Zn isotopes from the (d,^{3}He) reaction, but it can be deduced from the results[11)] of the (^{3}He,d) reaction on ^{68,70}Zn that the number of protons on the p orbitals lies between 1.5 and 2. In the Ga isotopes, with Z=31, there is still an important filling of the p orbitals and the f5/2 occupancy remains weak. It appears therefore that the p orbitals, empty at Z=28, begin to fill normally, up to and including the Ga isotopes (Z=31). In the Ge and As isotopes, with Z=32 and 33, the p orbitals though far from being filled, do not continue to fill as they normally should and the additional protons go entirely on the f5/2 orbital. This first anomaly appears therefore to occur between Z=31 and 32.

On the other hand, when crossing the N=40→42 transition first observed in the (t,p) reaction7), it appears that one proton which was previously on the p orbitals goes also to the f5/2 orbital.

We have therefore evidences in our data for two different, but perhaps related, types of anomalies :

i) When increasing Z, for a constant N value, the p orbitals begin to fill normaly, at least for N<40, then these orbitals apparently completely stop filling between Z=31 and 32 and all the additional protons go on the f5/2 orbital.

ii) When increasing N, for a constant Z value, the populations of the p and f5/2 orbitals change only when crossing the transition between N=40 and 42 : a proton which was on the p orbital then jumps to the f5/2 orbital.

5.2. Comparison with model wave functions.

A very simple model, based on configuration mixing of protons on the p3/2 and f5/2 orbitals, has already been proposed2,3) for the $Ga_{g.s}$ and for the $Ge_{g.s}$ and Ge0^+_2 wave functions. It has been used successfully to reproduce or predict many experimental results20). The main features are summarized below :

i) Using the occupation numbers determined in the $^{71}Ga(d,^3He)^{70}Zn$ reaction5) it has been possible to get the coefficients of the $^{71}Ga_{g.s}$ wave function

$$\psi(^{71}Ga.g.s) = \sqrt{0.87}\ (p_{3/2})^3 + \sqrt{0.13}.\ p_{3/2}.\ (f_{5/2})^2_0$$

ii) Using the known ratio of the spectroscopic factors for the two 0^+ levels of ^{72}Ge it is then possible to determine (see ref.3).

$$\psi(^{72}\mathrm{Ge\ g.s}) = \sqrt{0.37}\,(p_{3/2})^4_0 + \sqrt{0.63}\,(p_{3/2})^2_0\,(f_{5/2})^2_0$$

$$\psi(^{72}\mathrm{Ge}\ 0^+_2) = \sqrt{0.63}\,(p_{3/2})^4_0 - \sqrt{0.37}\,(p_{3/2})^2_0\,(f_{5/2})^2_0$$

iii) It is then possible (see ref. 3) using the known ratio$^{6)}$ of the cross sections of the two 0^+ levels of ^{72}Ge in the (p,t) reaction, to determine

$$\psi(^{74}\mathrm{Ge\ g.s}) = \sqrt{0.03}\,(p_{3/2})^4_0 + \sqrt{0.97}\,(p_{3/2})^2_0\,(f_{5/2})^2_0$$

$$\psi(^{74}\mathrm{Ge}\ 0^+_2) = \sqrt{0.97}\,(p_{3/2})^4_0 - \sqrt{0.03}\,(p_{3/2})^2_0\,(f_{5/2})^2_0$$

It is interesting to see whether or not these wave function, determined before the experiments described in the present paper, are able to reproduce the measured occupation numbers. If we compare the experimental and model values for the p (p1/2+p3/2) and f5/2 orbitals, we get a rather good agreement (see table 10). It is clear however that our simplifying hypothesis that the p1/2 and g9/2 orbitals are empty is not absolutely correct. The probability of occupation of the g9/2 orbital is however very small and we shall continue to neglect it. It proves that a very simple modification permits to account for the p1/2 occupation number. The results called "improved model" in table 10 are simply obtained by admitting that in the second term $(p^2(f5/2)^2_0)$ of the Ge wave functions the p particles are not all p3/2, but that a fraction (1/3 in ^{72}Ge,1/4 in ^{74}Ge) is in fact p1/2. This minor improvement has only miner effects on the results reported previously$^{20)}$.

It is attractive to try to determine the coefficients of the $^{73}\mathrm{Ga}_{\mathrm{g.s}}$ wave function

$$\psi(^{73}\text{Ga g.s}) = \alpha(p_{3/2})^3 + \beta.\ p3/2\ (f_{5/2})^2_0$$

Unfortunately the value of the $^{74}\text{Ge}_{g.s}(d,{}^3\text{He})^{73}\text{Ga}_{g.s}$ spectroscopic factor proves not to depend sensitively upon the values of the α and β coefficients. We may however proceed like in the case of the wave function of $^{74}\text{Ge}_{g.s}$ (see ref.3) and try to reproduce the quite strikingly reduced value of the overlap of the ground states wave functions observed[7)] in the $^{71}\text{Ga}(t,p)^{73}\text{Ga}$ reaction. A good agreement (0.27 to be compared to an experimental value of 0.31) is obtained using the same coefficients as in the $^{74}\text{Ge}_{g.s}$ wave function, namely

$$\psi(^{73}\text{Ga g.s}) = \sqrt{0.03}\ (p_{3/2})^3 + \sqrt{0.97}.p_{3/2}\ (f_{5/2})^2$$

With these coefficients the spectroscopic factor for the $^{74}\text{Ge}_{g.s}(d,{}^3\text{He})^{73}\text{Ga}_{g.s}$ is computed as 1.56 to be compared with an experimental value of 1.33.

The wave functions discussed above are, at least, a parametrization of the experimental results. They permit to see that the main change occurring between $^{72}_{40}\text{Ge}$ and $^{74}_{42}\text{Ge}$, as well as between $^{71}_{40}\text{Ga}$ and $^{73}_{42}\text{Ga}$, corresponding to the N=40→42 transition, is the near disappearance of the first term of the wave functions, containing respectively 4 and 3 p3/2 protons in the Ge and Ga isotopes.

6. Summary and conclusion.

The study of the $^{69,71,73,75}\text{Ga}$ isotopes by means of the $(d,{}^3\text{He})$ reaction at 26 MeV has permitted to measure the spectroscopic factors for many levels and to determine the level schemes of the practically unknown ^{73}Ga and ^{75}Ga.

The occupation numbers measured here for the even-even $^{70,72,74,76}\text{Ge}$ isotopes and previously for the odd nuclei $^{69,71}\text{Ga}$ and ^{75}As reveal, instead of the usual smooth behaviour as a function of N and Z, two striking anomalies.

When increasing Z, for a constant N value (<40), the p orbitals begin to fill normally, then completely stop filling, though far from being filled, between Z=31 and 32, and all the additional protons go on the f5/2 orbital.

When increasing N, for a constant Z value, the populations of the p and f5/2 orbitals change only when crossing the transition between N=40 and 42, then a proton which was on the p orbital jumps to the f5/2 orbital.

This last anomaly is clearly related to the structural transition observed[7)] between N=40 and 42 for the Ge and Ga isotopes, in a comparison of the (p,t) and (t,p) reactions.

We do not know yet the exact origin of the observed anomalies, but they could well be related to changes of the nuclear shape.

The occupation numbers measured are rather well reproduced by a slightly improved version of our model describing to Ga ground states and the 0^+ levels of the Ge isotopes as configuration mixing of protons in the p and f5/2 orbitals. The main change in these wave functions both for Ge and Ga, when crossing the N=40→42 transition, is the near disappearance of the term containing more than 2 particles in the same orbital. Such an effect could be an indication that the transition is a "spherical→deformed" one, as suggested on the basis of the comparison of the (p,t) and (t,p) results, because in a deformed nucleus (Nilsson model for example) no more than 2 particles can couple on a given intrinsic orbital.

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TABLE 1 - ISOTOPIC COMPOSITION OF THE TARGETS

target \ isotope	^{70}Ge	^{72}Ge	^{73}Ge	^{74}Ge	^{76}Ge	thickness μg/cm^2
^{70}Ge	84.62	5.54	1.47	6.36	2.01	52
^{72}Ge	1.04	96.23	.77	1.63	.33	60
^{74}Ge	1.71	2.21	.9	94.48	.70	60
^{76}Ge	.81	1.21	.50	1.98	95.5	67
natural	20.52	27.43	7.76	36.54	7.76	60

TABLE 2 - Q VALUES FOR Ge(d^{3}He) Ge REACTION

Reaction	$^{70}Ge(d^3He)^{69}Ge$	$^{72}Ge(d^3He)^{71}Ge$	$^{74}Ge(d^3He)^{73}Ge$	$^{76}Ge(d^3He)^{75}Ge$
Previously known Q values a) (in keV)	-3.035.4±3.2	-4.236.5±3.0	-5.486±40	-6.460±200
measured Q (in keV)	-3.030 ± 7	-4.241 ± 7	-5.515±7	-6.545±7

a) from ref. 9

TABLE 3 : OPTICAL AND BOUND STATE POTENTIAL PARAMETERS USED IN THE DWBA ANALYSIS

	V	r_o	a	w	$4W_D$	r'_o	a'	r_{oc}
d a)	$81-.22E+2Z/A^{1/3}$	1.15	.81	0	$57.6+.96E$	1.34	.68	1.15
^{3}He b)	$151.9-.17E+50(N-Z)/A$	1.20	.72	$41.7-.33E+$ $44(N-Z)/A$	0	1.4	.88	1.3
p		1.25	.65	0	0			1.25

a) from ref.13

b) from ref.12

TABLE 4 : RESULTS FROM THE ^{70}Ge(d^{3}He)^{69}Ga REACTION

Previous work a)		present work			
E_x(keV)	J^π	E_x(keV)	l	J^πassigned	C^2S b)
0	$3/2^-$	0	1	$3/2^-$	1.63
318.5	$1/2^-$	317	1	$1/2^-$	.49
573.8	$5/2^-$	571	3	$5/2^-$	1.14
871.8	$3/2^-$	873	1	$3/2^-$	.58
1027.	$1/2^-$	1029	1	$1/2^-$	.10
1106.3	$5/2^-$	1108	3	$5/2^-$	.10
1336.0	$7/2^-$	1335	3	$7/2^-$	.49
1487.7	$7/2^-$	1488	3	$7/2^-$	.24
1525.4	$(3/2,5/2)^-$				
1723.4	$5/2^-$				
1764.9	$9/2^-$				
1891.1	$3/2^-$	1890	1	$3/2^-$	.145
1923.2	$7/2^-$	1923	3	$7/2^-$	.23
1972.0	$9/2^+$	1970	4 +	$9/2^+$	.26
1978.	$(1/2^-,3/2^-)$		1	$1/2^-,3/2^-$	.033, .026
2002.	$(1/2^-,3/2^-)$				
2022.4	$5/2^-,7/2^-$				
2042.8	$(3/2^-,5/2)^-$				
2197					
2220	$1/2^+$				
		2250	(1)	$(1/2^-,3/2^-)$	(.037, .03)
2352					
2426		2425	3	$7/2^-,(5/2^-)$	1.42, (.81)
2457	3/2	2461	(3)	$(7/2^-,5/2^-)$	(.23, .13)

a) from ref. 14

b) When there are two possible J^π assignments, the corresponding spectroscopic factors are given in the same order.

Table 5 - RESULTS FROM THE ^{72}Ge (d,^{3}He)^{71}Ga REACTION

Previous works a)		Present work			
E_x(keV)	J^π	Ex(keV)	l	J^π assigned	C^2S b)
0	$3/2^-$	0	1	$3/2^-$	2.14
389.9	$1/2^-$	388	1	$1/2^-$	.04
487.3	$5/2^-$	487	3	$5/2^-$	1.14
511.5	$3/2^-$	510	1	$3/2^-$	.21
910.3	$3/2^-,(1/2^-)$	(910)			<.01
964.7	$5/2^-$	964	3	$5/2^-$	.20
1107.5	$7/2^-$				
1109	$1/2^-$	1113	1	$1/2^-$	.39
1395.2	$(5/2^-,7/2^-)$	1396	3	$7/2^-,(5/2^-)$	.52,(.92)
1476.1	$5/2^-,7/2^-$	1476	3	7/2,5/2	.12, .21
1493.8	$9/2^+$	1495	4	$9/2^+$	.24
1498.7	$5/2^-,7/2^-$				
1631.5	$3/2^-(1/2^-)$	1634			very weak
1702.1					
1719.7	$(5/2^-,7/2^-)$				
		1907	3	$7/2^-,(5/2^-)$	.87,(1.59)
		1995	3	$7/2^-,(5/2^-)$	.37,(.65)

a) from ref. 16

b) When there are two possible J^π assignments, the corresponding spectroscopic factors are given in the same order.

TABLE 6 - RESULTS FROM THE ^{74}Ge(d,^{3}He)^{73}Ga REACTION

Previous works			Present work			
$E_x$$^{a)}$ (keV)	J^{π} $^{a)}$	$E_x$$^{b)}$ (keV)	Ex (keV)	1	J^{π}assigned	$C^2S$$^{c)}$
0	$3/2^-$	0	0	1	$3/2^-$	1.33
			198	3	$5/2^-,(7/2^-)$	1.87 (1.06)
219	$3/2^-$	216	214	1	$3/2^-$	.07
498		496	495	3	$5/2^-(7/2^-)$	.32,(.18)
647						
915	$3/2^-$	911	912	1	$3/2^-$	.04
956			952	3	$7/2^-,(5/2^-)$	.50(.89)
1117			1112	1	$1/2^-(3/2^-)$	.43,(.35)
1235			1233	(4)	$(9/2^+)$	(.37)
1396						
1528		1	1534	3	$7/2^-,(5/2^-)$	1.79(3.15)
1578						
1618			1620	3	$7/2^-,(5/2^-)$	.50,(.91)
1771			1777	(3)	$(7/2^-,5/2^-)$	(.21, .36)
1800	$3/2^-$					

a) From ref. 7

b) From ref. 16

c) When there are two possible J^{π} assignments, the corresponding spectroscopic factors are given in the same order.

TABLE 7 : Results from the ^{76}Ge(d,^{3}He)^{75}Ga REACTION

	Present work			
Exc$^{a)}$ (keV)	Exc	l	J^{π} assigned	C^2S
	0	1	$3/2^-$	
	180	1	$3/2^-$, $1/2^-$	.06,.07
228	232	3	$5/2^-$,$(7/2^-)$	2.44,(1.35)
432		(1)		< .03
		(3)		< .1
606		(1)		< .03
		(3)		< .1
	887	3	$7/2^-$,$(5/2^-)$	.39,(.69)
	1174	3	$7/2^-$,$5/2^-$	.10, .18
	1263	1	$1/2^-$,$(3/2^-)$	.40,(.32)
	1517	(4)	$(9/2^+)$	.25
	1553	3	$7/2^-$,$5/2^-$	.10, .17
	1629	3	$7/2^-$,$(5/2^-)$	.43,(.73)
	1942	1	$3/2^-$,$1/2^-$	.11, .09
	1976			
	2023	3	$7/2^-$,$(5/2^-)$	2.7,(5.1)
	2090			

a) from ref. 17

Table 8 : Summed spectroscopic strengths, centroids of the observed strengths (in keV) and proportion of the observed strengths (and of the total strengths for $7/2^-$) in the strongest level.

Shell \ N	38	40	42	44
2p1/2	.59,439,.83	.43,1042,.91	.43,1117,1	.40,1236,1
2p3/2	2.36,331,.69	2.35,46,.91	1.44,36,.91	1.25,148,.88
1f5/2	1.24,618,.92	1.34,559,.85	2.20,242,.85	2.44,232,1
1f7/2	1.77,1932,.46 (.10)	1.88,1755 .35 (.11)	3.00,1468, .6 (.22)	2.72,1823, .73 (.34)
1g9/2	.25,1972,1.	.24,1494,1	(.37),(1235)(1)	.25,1517,1
p1/2+p3/2+f5/2	4.19	4.12	4.07	4.09

Table 9 : Comparison of the 1f5/2 and the 2p occupation numbers obtained by means of (d,^{3}He) reaction on ^{69,71}Ga, $^{70-76}$Ge and ^{75}As targets. The main feature seems to be that the additionnal proton (when the target varies from Ga to Ge and from Ge to As) goes on the f5/2 orbit and that another proton goes from the p to the f orbit when N changes from 40 to 42.

Z \ N	38	40	42	44	
Ga 31	2.54	2.76			
Ge 32	2.95	2.78	1.87	1.65	l = 1
As 33			1.80		
Ga 31	.38	.25			
Ge 32	1.24	1.34	2.20	2.40	l = 3
As 33			3.42		

Table 10 : Comparison of experimental and calculated occupation numbers

		<f5/2>	<p>	<p1/2>	<p3/2>
72	Exp	1.34	2.78	0.43	2.35
	Old Model	1.26	2.74	0	2.74
	Model Improved	1.26	2.74	0.42	2.32
74	Exp	2.2	1.87	0.43	1.44
	Old Model	1.94	2.06	0	2.06
	Model Improved	1.94	2.06	0.48	1.58

Figure captions

Fig. 1 : Typical energy spectra of emitted ^{3}He from the ^{74,76}Ge(d,^{3}He)^{73,75}Ga reaction. Peaks without indication of excitation energy result from (d,^{3}He) reaction either on other Ge isotopes or on light impurities. The broad peak on each spectrum results from the ^{16}O(d,^{3}He)^{15}N$_{g.s.}$ reaction.

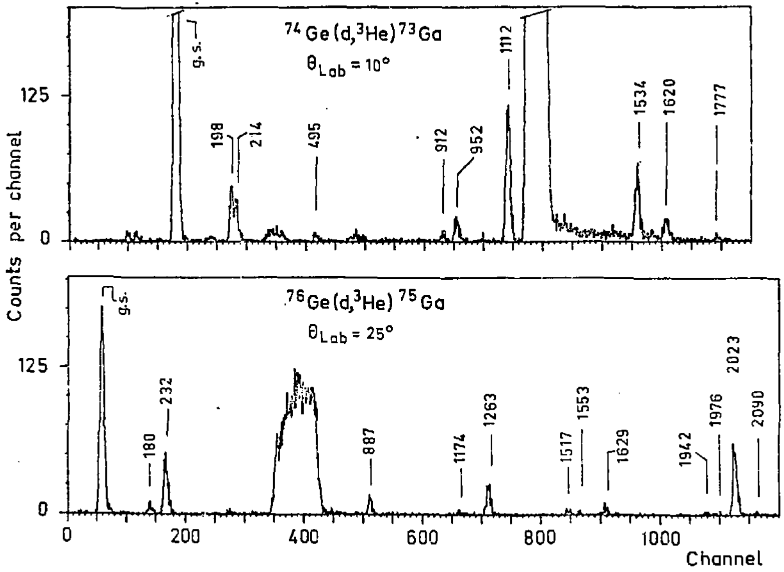
Fig. 2 : Angular distributions of the ^{3}He particles in the ^{70}Ge(d,^{3}He)^{69}Ga reaction. The curves are the results of D.W.B.A. calculations.

Fig. 3 : Angular distributions of the ^{3}He particles in the ^{72}Ge(d,^{3}He)^{71}Ga reaction. The curves are the results of D.W.B.A. calculations.

Fig. 4 : Angular distributions of the ^{3}He particles in the ^{74}Ge(d,^{3}He)^{73}Ga reaction. The curves are the results of D.W.B.A. calculations.

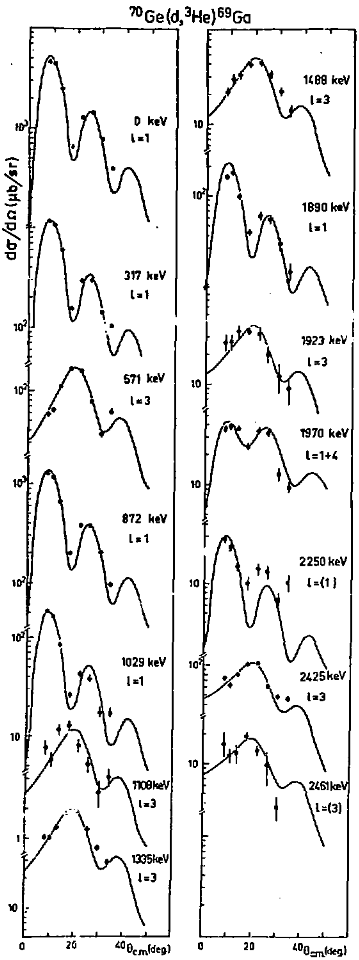
Fig. 5 : Angular distributions of the ^{3}He particles in the ^{76}Ge(d,^{3}He)^{75}Ga reaction. The curves are the results of DWBA calculations.

Fig. 6 : Comparison of levels schemes for the Ga isotopes obtained in one-proton transfer reactions on even nuclei. For each isotope the right-side bars represent spectroscopic strengths $(2J+1)C^{2}S$ for stripping reaction (ref.11), the left-side bars represent spectroscopic strengths $C^{2}S$ for pick-up reaction (this work). Solid bars correspond to $l=1$ transfers, open bars to $l = 3$ transfers, crosses to $l = 4$ transfers. The total length of a line corresponds to a spectroscopic strength value of 5. Levels carrying the major part of each angular momentum transfer are connected by dotted lines



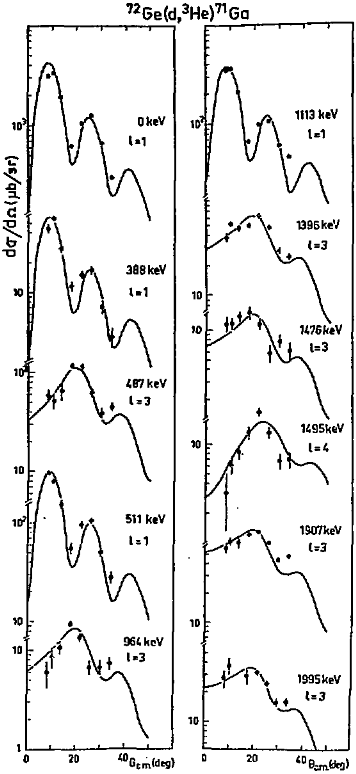
$^{74}Ge(d,^{3}He)^{73}Ga$
$\theta_{Lab} = 10°$
g.s.
198
214
495
912
952
1112
1534
1620
1777
$^{76}Ge(d,^{3}He)^{75}Ga$
$\theta_{Lab} = 25°$
g.s.
180
232
887
1174
1263
1517
1553
1629
1942
1976
2023
2090
Counts per channel
125
0
125
0
0
200
400
600
800
1000
Channel

Fig.1.



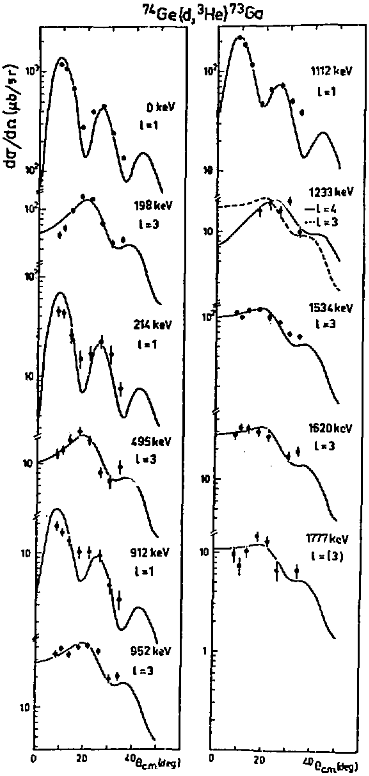
^{70}Ge(d,^{3}He)^{69}Ga
dσ/dΩ (μb/sr)
0 keV
l=1
317 keV
l=1
571 keV
l=3
872 keV
l=1
1029 keV
l=1
1108keV
l=3
1335keV
l=3
1488 keV
l=3
1890 keV
l=1
1923 keV
l=3
1970 keV
l=1+4
2250 keV
l=(1)
2425keV
l=3
2461keV
l=(3)
10^3
10^2
10
1
0
20
40
θ$_{c.m.}$(deg)

Fig.2.



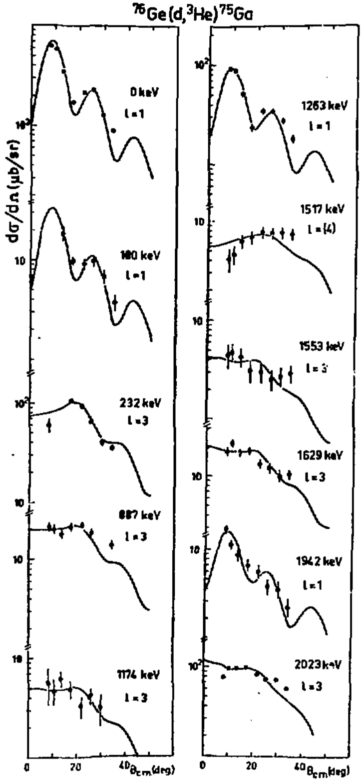
^{72}Ge(d,^{3}He)^{71}Ga
dσ/dΩ (μb/sr)
0 keV
l=1
388 keV
l=1
487 keV
l=3
511 keV
l=1
964 keV
l=3
1113 keV
l=1
1396 keV
l=3
1476 keV
l=3
1495 keV
l=4
1907 keV
l=3
1995 keV
l=3
10^3
10^2
10
1
0
20
40
θc.m.(deg)

Fig.3.



74Ge(d,3He)73Ga
dσ/dΩ (μb/sr)
0 keV
l = 1
198 keV
l = 3
214 keV
l = 1
495 keV
l = 3
912 keV
l = 1
952 keV
l = 3
1112 keV
l = 1
1233 keV
— l = 4
--- l = 3
1534 keV
l = 3
1620 keV
l = 3
1777 keV
l = (3)
0
20
40 θcm(deg)

Fig.4.



^{76}Ge(d,^{3}He)^{75}Ga
dσ/dΩ (μb/sr)
0 keV
l = 1
180 keV
l = 1
232 keV
l = 3
887 keV
l = 3
1174 keV
l = 3
1263 keV
l = 1
1517 keV
l = (4)
1553 keV
l = 3
1629 keV
l = 3
1942 keV
l = 1
2023 keV
l = 3
10²
10
0
20
40
θcm(deg)

Fig. 5.

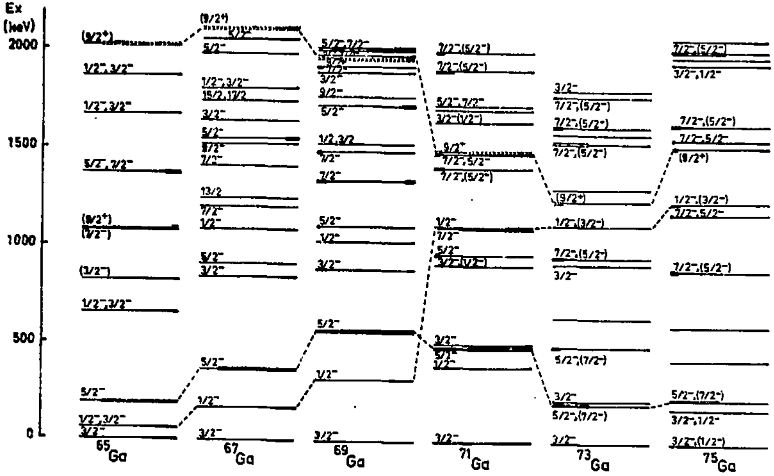

Ex
(keV)
2000
1500
1000
500
0
(9/2+)
1/2−,3/2−
1/2−,3/2−
5/2−,7/2−
(9/2+)
(7/2−)
(1/2−)
1/2−,3/2−
5/2−
1/2−,3/2−
3/2−
65Ga
(9/2+)
5/2−
5/2−
1/2−,3/2−
15/2,17/2
3/2−
5/2−
7/2−
7/2−
13/2
7/2−
1/2−
5/2−
3/2−
5/2−
1/2−
3/2−
67Ga
5/2−,7/2−
7/2−
3/2−
9/2−
5/2+
1/2,3/2
7/2−
7/2−
5/2−
1/2−
3/2−
5/2−
1/2−
3/2−
69Ga
7/2−,(5/2−)
7/2−,(5/2−)
5/2−,7/2−
3/2−(1/2−)
9/2+
7/2−,5/2−
7/2−,(5/2−)
1/2−
7/2−
5/2−
3/2−(1/2−)
3/2−
5/2−
1/2−
3/2−
71Ga
3/2−
7/2−,(5/2−)
7/2−,(5/2−)
7/2−,(5/2−)
(9/2+)
1/2−,(3/2−)
7/2−,(5/2−)
3/2−
5/2−,(7/2−)
3/2−
5/2−,(7/2−)
3/2−
73Ga
7/2−,(5/2−)
3/2−,1/2−
7/2−,(5/2−)
7/2−,5/2−
(9/2+)
1/2−,(3/2−)
7/2−,5/2−
7/2−,(5/2−)
5/2−,(7/2−)
3/2−,1/2−
3/2−,(1/2−)
75Ga

Fig.6.