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EXPERIMENTAL EVIDENCES FOR J - DEPENDENCE IN(^{3}He, α) - REACTIONS ON 1p - SHELL NUCLEI

By

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SUMMARY

The experimental data of several authors for the reaction (^{3}He, α) on the 1p - shell nuclei at E(^{3}He) = 31 MeV are used to study the J - dependence between the obtained experimental angular distributions for the corresponding excited states. Two methods are used to show the J - dependence phenomenon. The first method is to compare the forms of different experimental angular distributions having the same transferred total angular momentum. The second method is to compare the experimental cross - section - ratio curves for the different excited states of a nucleus having the same transferred orbial angular momentum. A good J - dependence could be obtained between the different angular distributions in this reaction. Our results coincided with what previously found experimentally and predicted theoretically.

Table 2 : The binding energies for the last neutron and the Q-values for the (^{3}He,α_0)-reactions of the 1p-shell nuclei, (Gove and Wapstra 1972).

Target nucleus	Final nucleus	Binding energy of neutron in target (MeV)	Q-value for (^{3}He,α_0)-reaction (MeV)
^{7}Li	^{6}Li	7.2525	13.3255
^{9}Be	^{8}Be	1.6651	18.9123
^{10}B	^{9}B	8.4352	12.1433
^{11}B	^{10}B	11.456	9.1225
^{12}C	^{11}C	18.7219	1.8566
^{13}C	^{12}C	4.9464	15.632
^{14}N	^{13}N	10.5536	10.0249
^{15}N	^{14}N	10.8337	9.7448
^{16}O	^{15}O	15.6694	4.909
^{17}O	^{16}O	4.1424	16.4361
^{18}O	^{17}O	8.0468	12.5317
^{19}F	^{18}F	10.4307	10.1478
^{20}Ne	^{19}Ne	16.8655	3.713
^{21}Ne	^{20}Ne	6.7612	13.8173
^{22}Ne	^{21}Ne	10.3656	10.2128

of the spins of the final states. The vector analyzing power in one - nucleon transfer reactions is sensitive to the value of the angular momentum transfer J_{tr} (5). Also by comparing the shapes of the experimental angular distributions with one state or with a group of states of known spin in a nuclear reaction or by comparing the shapes of the curves of the experimental reaction cross - section ratios (1 4, 6, 7), the spins of the final excited states and the predominant component of transferred total angular momentum J_{tr} could exactly determined.

The J - dependent effects also have been proposed to be attributed to the contributions of two - step processes of the reaction amplitude. For example the standard DWBA - calculations for cross - section of the reaction ^{30}Si (d, p) ^{31}Si at 10 MeV to the two ^{31}Si 2.32 MeV $(3 / 2)^+$ and 2.79 MeV $(5 / 2)^+$ states and the calculations for both states including the two - step processes through the lowest 2^+ state of ^{30}Si do not agree with the experimental data (8). Contrary to that the calculations including the two - step process via the $1/2^+$ state of ^{31}Si at 0.75 MeV are in excellent agreement with the experimental data in the forward direction. Thus the inclusion of the two - step contribution (coupled reactions channels) to this reaction is able to give a very good account of all the J - dependence of the cross - sections to $3/2^+$ and $5/2^+$ states of ^{31}Si.

Experimental measurements of (p, α) - nuclear ractions on 1p - shell - (9, 10) and 2s - 1d - shell - nuclei (11) and also (d, p) and (^{3}He, α) - reactions on 1p - shell - (12), 2s - 1d - shell - (1, 13, 14) and 2d - shell nuclei (13), showed that the J - dependence and the form of the angular distribution are independent of target nucleus, excitation energy and reaction Q - value.

In the present work two methods for studying the J - dependence in the (^{3}He, α) reactions on the 1p - shell nuclei have been used. The first one is to compare the forms of different experimental angular distributions having the same predominant component for the transferred total angular momentum. The second method is also to compare different experimental reaction cross-section ratios for excited states having the same transferred orbital angular momentum L_{tr} (^{3}).

EXPERIMENTAL DATA

The experimental data of the reaction (^{3}He, α) on the nuclei ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{14}N and ^{15}N are taken at invident ^{3}He - energy of 26.7, 33.7, 33.0, 35.65, 27.3, 25.4 and 39.8 MeV respectively (^{15} - ^{19}). The corresponding experimental angular distributions with transfer total angular momentum J_{tr} (n) = 1/2, 3/2 and (5/2, 7/2) are shown in figs. 1, 2 and 3 respectively.

ANGULAR DISTRIBUTIONS FOR THE (^{3}He, α) - REACTIONS ON 1p - NUCLEI

The form of the angular distribution in a nuclear reaction is dependent on the direct component of it's mechanism. While the incident energies in the case of the (^{3}He, α) - reactions on 1p - reactions on 1p - shell nuclei are relatively high, they proceed predominantly by dircet neutron pick - up mechanism (^{20}) and the form of the angular distribution becomes unchangeale. The transferred neutron in the case of these reactions is picked up from the 1p - shell, i. e. the transferred orbital angular momentum $L_{tr}(n)=1$ and there are two values for the transferred total angular momentum J_{rt} (n) = 1/2 or 3/2. Therefore the theoretical calculations for the coefficients of fractional parentage (CFP) of one - particle transfer reactions made by Cohen and Kurath using the shell model wave functions ([21]) for the natural parity states of the 1p - shell nuclei give two components for most states, one belongs to J_{tr} (n) = 1/2 and the other to J_{tr} (n) = 3/2. It is also possible for a state to contain one component only either with J_{tr} (n) 1/2 or with $J_{tr}(n)=3/2$. Table (1) presents for each excited state the percentage for predominant component of J_{tr} (n), the corresponding Q - value, the experimental - ([22]) and calculated excitation energy.

a) The states with J_{tr} (n) = 1/2 :

In fig. (1) we have plotted the angular distributions for all excited states with J_{tr} (n) = 1/2. For most of these excited states the percentage for J_{tr} (n) = 1/2 are 100% ([21]). The curves for the ^{10}B 0.718 and 5.164 MeV states are almost identical. The angular distribution for the ^{10}B 3.578 MeV state is identical with the other pervious two distributions in the forward direction ($\theta_{C.M.} < 20°$). The angular distribution for the ^{12}C g.s. state is identical too to that of the ^{11}C 2.00 MeV state. As an exception is the position of the minimum at 70° in the ^{12}C g.s.'s angular distribution and at ~ 60° in the ^{11}C 2.0 MeV state's angular distribution. The minimum in the angular distribution of the ^{13}N g.s. at $\theta_{C.M.} = 70°$ is deeper than that at the same position in the distribution of the ^{11}C 2.00 MeV state, the identity between these two distributions in forward direction (8° - 70°) is very clear. The angular distribution for the ^{12}C 7.654 MeV state has a different form to that of the ^{12}C g.s., while it is not a 1p - state (^{21}) and probably has a different mechanism from the direct one. It is also clear that the two distributions for the ^{14}N g.s. and 2.313 MeV states have the same form exactly.

The reaction - mechanism at backward angles is probably due to another direct mechanism (heavy particle - pick - up or heavy particle knock-out Mechanism). In some distributions with J_{tr} (n) = 1/2 there is a deep minimum at $\theta_{C.M.}$ ~ 60° - 80°, which is a special character for the angular distributions with J_{tr} (n) = L_{tr} (n) -1/2 result in the one - particle - transfer nuclear reactions on light and medium weight targets ($^{1, 13, 14, 23, 24}$).

b) The states with J_{tr} (n) = 3/2 :

In fig. (2) all angular distributions for the excited states with J_{tr} (n) = 3/2 are presented Comparing the shapes of the angular distributions for states for which J_{tr} (n) = 1/2 with those having J_{tr} (n) = 3/2 for the same nucleus as shown in fig. (4), we find that the angular distributions with J_{tr} (n) = 1/2 oscillate more sharply than that with J_{tr} (n) = 3/2 for all nuclei under our concern, although they have the same steepness. The positions of the second and third maxima in the angular distributions for the states with J_{tr} (n) = 1/2 shifted to larger angels in comparison with their positions in the angular distributions with J_{tr} (n) = 3/2 for the residual nuclei ^{8}Be and ^{11}C and to smaller angles in the cases of ^{10}B and ^{14}N (see fig. 4).

The identity between the forms of the angular distributions with J_{tr} (n) = 3/2 devoted to the same nucleus is clear. As examples for the excited states having J_{tr} (n) = 3/2 are the ^{8}Be 16.922 and 17.64 MeV states, they are identical in the forward direction (6° - 85°) and the positions of maxima and minima are the same in both cases. The angular distribution for the ^{8}Be 19.07 MeV state has the same structure as those for the above two excited states and the position of the first maximum in these three distributions of ^{8}Be with J_{tr} (n) = 3/2 is at the same forward angle but it is somewhat broader in the case of the higher state. The positions for the other maxima and minima in case of the 19.07 MeV state are shifted ~ (8° - 10°) to larger angles. The change of the structure for the angular distributions of the three 3/2 - states of ^{8}Be is probably due to the different percentage of their J_{tr} (n) = 3/2 - component. The change in Q - values for the ^{8}Be 16.922, 17.64 and 19.07 MeV states can't give such different structures.

For the reaction ^{10}B (^{3}He, α) ^{9}B the angular distributions for the g.s. and 2.361 MeV states are identical and have the same steepness as in fig. (2). The distribution of the 11.7 MeV state is different in form to that of the other two low laying excited states.

The experimental cross - section for the reaction ^{11}B (^{3}He, α) ^{10}B is measured only in forward direction ($\theta_{C.M.} < 60°$). The angular distributions for the four 3/2 - excited states g.s., 1.740, 2.154 and 4.774 MeV are identiacl in structure and have the same steepness, the last one is somewhat flat.

As shown in fig. (2) the experimental angular distributions for the two states 4.804 and 8.104 MeV in the reaction ^{12}C (^{3}He, α) ^{11}C are similar in form (in forward direction) and that for g.s. is somewhat steeper and due to the Q - value dependence there is phase difference between the angular distribution of g.s. and those for the 4.804 and 8.104 MeV states. The angular distribution for the ^{11}C 8.104 MeV state is completely different to the angular distribution for the 1/2$^-$ ^{11}C state at 2.00 MeV and similar to that of it's analogue ^{11}B 8.559 MeV state in the ^{12}C (t, α) ^{11}B reaction at nearly the same incident energy (33 MeV) (^{25}). In the one - step reaction ^{12}C (e, e`p) ^{11}B ($^{26, 27}$) the ^{11}B 8.559 MeV state was not populated at all. This indicactes that there is no direct transfer between the ^{12}C g.s. and both of the two analogue states the ^{11}C 8.104 MeV state and the ^{11}B 8.559 MeV state. The population of the third 3/2$^-$ state in ^{12}C (^{3}He, α) - and ^{12}C (t, α) - reaction must be due to indirect processes despite the obvious similarity of it's angular distribution to that of the direct pick - up 3/2 - states in the final nucleus. The ^{11}C 8.104 MeV state and it's analogue state in ^{11}B are assumed to be a p3/2 - hole in the second O$^+$ ^{12}C state at 7.654 MeV (^{28}) which confirmed later (^{26}) and whose structure is outside the 1p - shell.

The identity in the forward direction is clear between the forms of the four angular distributions for the excited states 4.439, 12.71, 15.11 and 16.106 MeV in the reaction ^{13}C (^{3}He, α) ^{12}C as shown in fig. (2). It is also clear that the steepness of the angular distributions decreases as the excitation energy increases. This also has been found in our case in the reactions ^{9}Be (^{3}He, α), ^{11}B (^{3}He, α) and ^{12}C (^{3}He, α).

The angular distributions for the ^{13}N 7.376 and 11.740 MeV states are identical in the forward direction (8° - 40°). In the case of the 3.502 MeV state of the same nucleus the values of the experimental cross - section in the forward direction (0° - 20°) is not reported, therefore the form of it's angular distribution is different from those of the 7.376 and 11.74 MeV states. The ^{13}N 7.376 MeV (5/2$^-$) state is due to knock - out mechanism of a neutron from the p3/2 - shell.

The angular distributions for the ^{14}N 3.948, 7.029 and 13.74 MeV states are identical as shown in fig. (2). The ^{14}N 9.172 and 10.432 MeV states are predicted theoretically by Cohen and Kurath as one state (^{21}). The new obtained angular distribution is similar in structure to that of the states 3.948, 7.029 and 13.74 MeV but the position of the first minimum in it shifted ~ 4° ti smaller angle in comparison with it's position in the 7.029 and 13.74 MeV states. A peak is formed at $\theta_{C.M.}$ = 70° in the (9.172 + 10.432) MeV state, which formed at $\theta_{C.M.}$ = (80° - 85°) in the other 3/2 - states of ^{14}N. A characteristic minimum is formed in these four 3/2 - states at $\theta_{C.M.}$ = (57° - 70°). The odd behaviour for the (9.172 + 10.432) MeV state is unknown.

c) The states with J_{tr} (n) = 5/2 or 7/2 :

The experimental angular distributions for the ^{11}C 4.319, 6.478 and 8.42 MeV states are plotted in fig. (3). Such states with J_{tr} (n) = 5/2 or 7/2 are p - shell forbidden in the reaction ^{12}C (^{3}He, α) ^{11}C, they are very weak states. The two angular distributions belonging to the two 5/2 - states at 4.319, and 8.420 MeV are dissimilar in form. Coupled channels - and / or coupled reactions channels calculations for the cross - sections of the ^{11}C 4.319, 6.478 and 8.420 MeV states in ^{12}C (^{3}He, α) - reaction (^{18}) and for their ^{11}B analogue states at 4.445 and 6.743 MeV in ^{12}C (t, α) - reaction at nearly the same incident energy (^{25}) and also the experimental data for the one - step reaction ^{12}C (e, e`p) (^{29}) indecate that the 5/2$^-$ and 7/2$^-$ states in the nuclei ^{11}C and ^{11}B in the (^3He, α) and (t, α) reactions on ^{12}C populated perdominantly by two - step process.

J - DEPENDENCE FOR THE (^{3}He, α) - ANGULAR DISTRIBUTIONS

The experimental angular distributions for the states with J_{tr} (n) = 1/2 or 3/2 in the (^3He, α) - reactions are plotted in figures (5) and (6) in groups according to their form. The form of the angular distribution depends on the incident energy (^{24}) and in comparison with other one - nucleon - transfer reactions it depends on reaction type, on the transferred orbital angular momentum L_{tr} and on the predominant component of the transferred total angular momentum J_{tr} and it's percentage. We compare the forms of experimental angular distributions for different excited states in both figures to show the J - dependence between them.

In fig. (5) we have three groups of states (A, B and C) with a predominant component of J_{tr} (n) = 1/2. The angular distributions of each group have the same form in the indicated angular range. The group (A) contains the angular distributions for the ^{10}B 0.718 and 5.164 MeV states. The group (B) contains those for the ^{14}N g.s. and 2.313 MeV states, the Q - values for these two states have a difference of ~ 2.0 MeV, this difference has no large effect in the form of the angular distribution. The percentage for the transferred total angular momentum of the g.s. and 2.313 MeV states are very high and nearly equal to each other. The goup (C) contains those for the states ^{11}C 2.00 MeV, ^{13}N g.s. and the ^{12}C g.s., their percentage for the component of the J_{tr} (n) = 1/2 are very high (100%) and their Q - values are different. This classification of states in groups is independent on the Q - value specially in the last group (C).

Fig. (6) has four groups of angular distributions with a predominant component for the J_{tr} (n) = 3/2. Each group also has it's special form in the indicated angular range. The group (A) contains the angular distributions for the ^{8}Be 16.922 and 17.64 MeV states, which have nearly the same Q - value. In spite of their different percentage they have the same form showing a J - dependence between them.

In group (B) in the same figure presented the angular distributions for the five excited states ^{9}B (g.s. and 2.361 MeV), ^{10}B (g.s. and 1.740 MeV) and ^{12}C (4.439 MeV), their Q - values are respectively 12.143, 9.782, 7.1225, 7.382 and 11.193 MeV. The percentage for the component of J_{tr} (n) = 3/2 for these excited states are very high (~ 100%). Owing to the nearly equal values for the Q - values (only exception is the value of the ^{10}B 1.740 MeV state) and the equal percentage for J_{tr} (n) = 3/2 for these five states, they have the same form of angular distributions.

The group (C) contains the four states ^{11}C (g.s.), ^{14}N (3.948, 7.029 and 13.74 MeV), they have the Q - values 1.857, 5.797, 2.716 and -3.995 MeV respectively. The percentage of the component of J_{tr} (n) = 3/2 for these states are very high (100%) and approxximately equal to each other. The experimental angular distributions for these four states have the same form in spite of their different Q - values.

The group (D) in fig. (6) contains the angular distributions for the states ^{10}B (2.154 MeV), ^{12}C (12.71, 15.11 and 16.106 MeV) and ^{13}N (7.376 and 11.74 MeV). Five states in this group have percentage of ~ 100% for the component of J_{tr} (n) = 3/2. The ^{13}N 7.376 MeV state is excited via a knock - out of a neutron from the p3/2 - shell and it's angular distribution is similar to that for the other states excited via simple picked - up neutron from the p3/2 - shell (figs. 2 and 6D). In spite of the mutuality between the Q - values of the states presented in the group (D), the corresponding angular distributions show a clear J - dependence as in figure.

The explanation for the groups of states have the same predominant component of the J_{tr} (n) in figs. (5) and (6) is that a definite component for the transferred total angular momentum represents a certain wave function for the transferred particle, which leads to a certain final state(s) for the residual nucleus with a fixed excitation energy, spin and nuclear radius. The variation of the nuclear radius and / or the variation of the percentatge for the predominant component of J_{tr} (n) from state to another in a nucleus is probably the reason for the groups of states. This means the J - dependence between a group of states is probably due to one of these two factors or to a combination between them or probably due to the similarity of the structures for the states contained in each group.

THE RATIOS OF THE EXPERIMENTAL CROSS-SECTIONS

In this section we use the Fulmer - Daehnick method (^{3}) to compare the cross section - ratio curves for the (^{3}He, α) - reaction on 1p - shell nuclei.

This method usually used for the transitions have the same transferred orbital angular momentum L_{tr} to accentuate the similarities and differences among their experimental angular distributions as a second method to showing the J - dependence ($^{3, 4, 14, 24}$). It is an important method to determining, correcting or fixing the spins of the final excited states of a nucleus.

In fig. (7a) we have plotted the curves for the experimental ratios $\sigma(3/2) / \sigma(1/2)$ versus the laboratory angle for the excited states in the reaction ^{9}Be (^{3}He, α) ^{8}Be. The notation R (3/5) for example means the ratio of the reaction cross - section for the state number 3 (E_x = 16.922 MeV in table 1) to that of the state number 5 (E_x = 18.150 MeV) of the residual nucleus ^{8}Be. The first two curves R (3/5) and R (4/5) are for the two states 16.922 and 17.64 MeV to that of the 18.15 MeV state. Both curves are identical and do not show a smooth behaviour but display clear strong oscillations and they have maxima at $\theta_{lab.}$ = 14°, 24° and 44°. The third curve R (6/5) for the 3/2 - state 19.07 MeV has a different form and the positions of the maxima are at $\theta_{lab.}$ = 21°, 43° and 59°. This means the structures, mechanisms and forms of angular distributions for the two ^{8}Be 3/2 - states at 16.922 and 17.64 MeV are similar and those of the 19.07 MeV state are different. This can also be shown in fig. (7b) where the two curves R (3/4) and R (6/4) as the $\sigma(3/2) / \sigma(3/2)$ - ratios for the 16.922 and 19.07 MeV states to that of the 17.64 MeV state is plotted. The curve R (3/4) at the top of this figure for the 16.922 MeV state shows a smooth ratio and that at the bottom for R (6/4) shows strong structure. The differences in Q - values are not sufficient to explain the J - dependence in the case of the

16.922 and 17.64 MeV states. The curves in fig. (7a) and that at the top of fig. (7b) show that, both of the two states at 16.922 and 17.64 MeV have the same structure, the same mechanism and the same form of angular distribution and those of the 19.07 MeV state are completely different. Therefore the ^{8}Be 16.922 and 17.64 MeV states show J - dependence as in fig. (6a).

For the reaction ^{10}B (^{3}He, α) fig. (8) presents the curve R (1/0) as the ratio σ(3/2) / σ(3/2) for the 2.361 MeV state to that of the g.s. which is a smooth ratio. This means the structure, mechanism and the form of the experimental angular distributions for both the ^{9}B g.s. and 2.361 MeV states are similar, this is enough to show J - dependence between them (see fig. 6B).

The experimental cross - section for the reaction ^{11}B (^{3}He, α) is measured only in the forward direction ($9° < \theta_{C.M.} < 60°$). The curves R (0/1), R (2/1), R (3/1) and R (5/1) are plotted in fig. (9a) as the σ(3/2) / σ(1/2) - ratios for the g.s., 1.74, 2.154 and 4.774 MeV states to that of the 0.718 MeV state. The first pair of curves R (0/1) and R (2/1) have three maxima at $\theta_{lab.}$ = 9°, 18° and 25° and they are identical to each other. The other pair of curves R (3/1) and R (5/1) are different from each other and they are also different from that for the previous pair of curves. There is some similarity of the curve R (3/1) to both the curves of the first pair. The curve R (5/1) has a different form and has strong oscillations. This is also clear in the curves R (2/0), R (3/0) and R (5/0) as the σ (3/2) / σ (3/2) - ratios for the 1.74, 2.154 and 4.774 MeV states to that of the g.s. as in fig. (9b), where the curves R (2/0) and R (3/0) are smooth and similar and that of

R(5/0) has another form especially for $\theta_{lab.} > 30°$. This means that the structure, mechanism and form of angular distributions for the g.s. and 1.74 MeV states are similar and those for the 2.154 MeV state are somewhat different from those of the g.s. and 1.74 MeV states. The 4.774 MeV state is different in form and structure from the other 3/2 - states. In fig. (9c) the curves R (4/1) and R (6/1) are plotted as the σ (1/2) / σ (1/2) - ratios for the 3.587 and 5.164 MeV states to that of the 0.718 MeV state. The curve R (4/1) appears to be more complex than the curve R (6/1). This means the 0.718 and 5.164 MeV states are similar in structure, mechanism and form of angular distributions while those of the 3.587 MeV state are different. Therefore a J - dependence is clear between the two 3/2 - states g.s. and 1.74 MeV (see fig. 6b) and also between the two 1/2 - states 0.718 and 5.164 MeV (see fig. 5a).

As we have mentioned earlier, the forms of the experimental angular distributions for the two 3/2 - states 4.804 and 8.104 MeV in the reaction ^{12}C (^3He, α) are similar (specially in forward direction) and different from that of g.s. . The forms of the three curves R (0/1), R (3/1) and R (5/1) as the $\sigma(3/2)$ / $\sigma(1/2)$ - ratios for the three states g.s., 4.804 and 8.104 MeV to that of the 2.00 MeV state are different in form as shown in fig. (10a). The distinctions of these ratio - curves means that the structures and mechanisms of these three 3/2 - states are different. This can also be exact established by plotting the curves R (3/0) and R (5/0) as the $\sigma(3/2)$ / $\sigma(3/2)$ - ratios for the 4.804 and 8.104 MeV states to that of the g.s. as in fig. (10b). These two curves have different forms which leads to the same previous result. The mechanism and structure of the 8.104 MeV state are confirmed experimentally and theoretically ($^{26-28}$). According to this, the population of the third 3/2$^-$ state in ^{11}C and ^{11}B in the two reactions ^{12}C(^{3}He,α) and ^{12}C(t,α) is due to indirect processes which is in agreement with our results.

In fig. (10c) we have plotted the curves R (4/2) and R (6/2) as the two ratios σ(7/2) / σ(5/2) and σ(5/2) / σ(5/2) for the 6.478 and 8.420 MeV states respectively to that of the 4.319 MeV state. These curves have different forms and while their angular distributions sepecially those belonging to the two 5/2 - states are dissimilar in form, this leads to the conclusion that the above three states have different structures and mechanisms different from the direct one. These three excited states in ^{11}C are populated predominantly in the ^{12}C (^{3}He, α) - reaction by two - step processes ($^{18, 25, 29}$) [see 3 (c)], which is also in agreement with our results.

The different structures and mechanisms for the 3/2$^-$ states g.s., 4.804 and 8.104 MeV and the excitation of the p - shell - forbidden (5/2$^-$ or 7/2$^-$) states 4.319, 6.478 and 8.42 MeV in the reaction ^{12}C (^{3}He, α) make the mechanism of this reaction and the structure of the residual nucleus ^{11}C difficult to understand. This leads to the conclusion, J - dependence between the experimental angular distributions of the ^{11}C - nucleus states is impossible.

In the reaction ^{13}C (^{3}He, α) the excited states 4.439, 12.71, 15.11 and 16.106 MeV have J_{tr} (n) = 3/2 and fig. (11a) presents the curves R (1/0), R (3/0), r (4/0) and R (5/0) as their σ(3/2) / σ(1/2) - ratios to that of the g.s. . The curves R (3/0), R (4/0) and R (5/0) are similar and have strong peaks at $\theta_{lab.}$ = 50°. This becomes clear when the curves R (4/3) and R (5/3) as the

$\sigma(3/2)$ / $\sigma(3/2)$ - ratios for the 15.11 and 16.106 MeV states to that of the 12.71 MeV state are plotted as in fig. (11b) which very slowly. The curve R(1/0) at the top of fig. (11a) has a strong peak with a broader top at $\theta_{lab.}$=46°. The strong peaks in the curves in fig. (11a) correspond to the fast fall of the cross - section values of the g.s. for $35° < \theta_{C.M.} < 60°$. This means that the ^{12}C 12.71, 15.11 and 16.106 MeV states have the same structure, the same mechanism and their angular distributions are similar, while the 4.439 MeV state is different in structure, in mechanism and in form of angular distribution (fig. 6).

Fig. (11c) presents the curve R (2 / 0) as $\sigma(1/2)$ / $\sigma(1/2)$ - ratio for the 7.654 MeV state to that of g.s., it is clear that this is a complex curve, which means the structures and mechanisms for both the two $1/2^-$ states are different (fig. 1). It is not clear to which theoretical state the ^{12}C 7.654 MeV state in ^{13}C (^3He, α) - reaction should correspond, since the second O^+ state of ^{12}C predicted theoretically (^{21}) is at 13.467 MeV. This indicates that this state is not a 1p - shell state and probably has a non - direct mechanism.

The angular distributions for the 1/2 - states g.s. and 2.313 MeV in ^{14}N (fig. 1) are similar and those for the 3/2 - states 3.948, 7.029 and 13.74 MeV (fig. 2) are also similar. Fig. (12a) presents the curves R (2/0), R (3/0), R (6/0) and R (18/0) as the $\sigma(3/2)$ / $\sigma(1/2)$ - ratios for the 3.948, 7.029, (9172 + 10.432) and 13.74 MeV states to that of the g.s. . There is a striking similarity between these four oscillatory curves, they have strong peaks at $\theta_{lab.}$ = 35° and two minima at $\theta_{lab.}$ = 15° and 52°. The identity between the forms of the angular distributions and structures for these 3/2 - states can be exactly understand using fig. (12b). The curves R (3/2), R (6/2) and R (18/2) are the $\sigma(3/2) / \sigma(3/2)$ - ratios for the 7.029, (9.127 + 10.432) and 13.74 MeV states to that of the 3.948 MeV state. These three curves have smooth ratios. Accordingly the J - dependence and the similarity of the structures and mechanisms for the 3.948, 7.029, (9.127 + 10.432) and 13.74 MeV states are clear. Owing to the odd behaviours fo the (9.127 + 10.432) MeV state it is omit in the J - dependence between these states (fig. 6c). Fig. (12c) shows the curve R (1/0) as the $\sigma(1/2) / \sigma(1/2)$ - ratio of the 2.313 MeV state to that of the g.s., which is a smooth curve. This means that the two 1/2 - states g.s. and 2.313 MeV are similar in structure and mechanism and have similar angular distributions and they show J - dependence (see fig. 5b).

In the case of the reaction ^{14}N (^3He, α) the experimental data for the cross - section is not enough to obtain such ratio curves of the excited states of the nucleus ^{13}N.

CONCLUSION

The experimental data for the reaction (^3He, α) on the 1p - shell nuclei at E (^3He) ~ 31 MeV are used to study the J - dependence phenomenon. According to the results of the two methods used in present work, the most excited states in this reaction have direct pick - up mechanisms, which are in good agreement with what previously predicted theoretically and found experimentally. The ^{11}C 4.319, 6.478 and 8.42 MeV states populated via two - step processes while the mechanism for the ^{11}C 8.104 MeV state is indirect process despite the obvious similarity of it's angular distribution to the other directly fed L_{tr} = 1 states. Theoretical calculations (^{28}) show that the last state is a p 3/2 - hole in the second O^+ ^{12}C state at 7.654 MeV which confirmed later experimentally, the structure of this state is outside the 1p - shell. Also the ^{12}C 7.654 MeV state is not a 1p - shell state. The ^{13}N 7.376 MeV state in the ^{14}N (^3He, α) - reaction results with a knock - out mechanism for the neutron from the 1p 3/2 - shell. These six excited states are exceptions of the direct pick - up mechanism in (^3He, α) - reation on 1p - shell nuclei. Therefore they didn't predicted by Cohen - Kurath calculations for the coefficients of fractional parentage (CFP) of one - particle transfer reactions ([21]).

As an explanation for the groups of states having the same component of the transferred total angular momentum is that a definite component for the transferred total angular momentum represents a certain wave function for the transferred particle, which leads to a certain final state(s) for the residual nucleus with a fixed excitation energy, spin and nuclear radius. The groups of states in figs. (5) and (6) are probably due to the dependence of the experimental angular distributions's form on the nuclear radii and / or on the percentage for the predominant component of the transferred total angular momentum (J_{tr}) of states in each group. A good combination between the nuclear radius and the percentage of the predominant component of J_{tr} for each excited state in a group of states is essential to show J - dependence between it's members. It is probable also that such groups (or the J - dependence phenomenon) are due to the similarity of the structures for the states in each group.

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Table (1)

The percentage for the predominant component, the calculated excitation energies E_x (cal.) of the natural parity excited states for the 1p-shell nuclei according to the calculations of the shell-model [21] and the corresponding Q-values.

Reaction E (^{3}He) MeV	Level No.	E_x (exp.) MeV [21]	J_f^π ; T_f [21]	Percentage. [21]	J_{tr} Component.	Q-value	E_x (cal.) MeV [21]
$^{9}\mathrm{Be}\ (^{3}\mathrm{He},\alpha)^{8}\mathrm{Be}$	4	16.922	2^+ ; 0+1	80.65	3/2	1.991	14.431
26.7	5	17.640	1^+ ; 1	51.04	3/2	1.273	16.881
	6	18.15	1^+ ; 0	73.10	1/2	0.763	14.979
	7	19.07	3^+ ; 1	100.00	3/2	-0.157	17.493
$^{10}\mathrm{B}(^{3}\mathrm{He},\alpha)^{9}\mathrm{B}$	0	g.s.	$3/2^-$; 1/2	100.00	3/2	12.143	0.000
33.7	1	2.361	$5/2^-$; 1/2	93.7	3/2	9.782	2.942
	3	11.700	$7/2^-$; 1/2	73.00	3/2	0.443	9.855
$^{11}\mathrm{B}(^{3}\mathrm{He},\alpha)^{10}\mathrm{B}$	0	g.s.	3^+ ; 0	100.0	3/2	9.123	0.000
33.0	1	0.718	1^+ ; 0	72.75	1/2	8.404	0.902
	2	1.74	0^+ ; 1	100.0	3/2	7.382	1.418
	3	2.154	1^+ ; 0	66.98	3/2	6.968	2.384
	4	3.587	2^+ ; 0	81.87	1/2	5.535	3.339
	5	4.774	3^+ ; 0	100.00	3/2	4.349	4.718
	6	5.164	2^+ ; 1	95.43	1/2	3.959	5.578
$^{12}\mathrm{C}(^{3}\mathrm{He},\alpha)^{11}\mathrm{C}$	0	g.s.	$3/2^-$; 1/2	100.0	3/2	1.857	0.000
35.65	1	2.000	$1/2^-$; 1/2	100.0	1/2	-0.143	1.708
	2	4.319 a	$5/2^-$; 1/2	-----	5/2	-2.462	----
	3	4.804	$3/2^-$; 1/2	100.0	3/2	-2.948	5.39
	4	6.478 a	$7/2^-$; 1/2	-----	7/2	-4.622	-----
	5	8.104 b	$3/2^-$; 1/2	-----	3/2	-6.248	-----
	6	8.42 a	$5/2^-$; 1/2	-----	5/2	-6.563	-----

To be cont.

Table (1) Cont.

$^{13}C(^{3}He,\alpha)^{12}C$ 27.3	0	g.s.	0^{+} ; 0	100.0	1/2	15.632	0.000
	1	4.439	2^{+} ; 0	100.0	3/2	11.193	4.648
	2	7.654 c	0^{+} ; 0	----	1/2	7.978	----
	3	12.710	1^{+} ; 0	99.85	3/2	2.922	12.449
	4	15.11	1^{+} ; 1	99.62	3/2	0.522	15.084
	5	16.106	2^{+} ; 1	100.00	3/2	-0.474	16.691
$^{14}N(^{3}He,\alpha)^{13}N$ 25.4	0	g.s.	$1/2^{-}$; 1/2	99.43	1/2	10.025	0.000
	1	3.502	$3/2^{-}$; 1/2	84.6	3/2	6.523	3.587
	2	7.376 d	$5/2^{-}$; 1/2	----	3/2	2.649	----
	8	11.74	$3/2^{-}$; 1/2	99.54	3/2	-1.715	14.004
$^{15}N(^{3}He,\alpha)^{14}N$ 39.8	0	g.s.	1^{+} ; 0	97.75	1/2	9.745	0.000
	1	2.313	0^{+} ; 1	100.00	1/2	7.432	2.690
	2	3.948	1^{+} ; 0	93.50	3/2	5.797	3.616
	3	7.029	2^{+} ; 0	100.00	3/2	2.716	6.991
	6	9.172 + 10.432	2^{+} ; 1 2^{+} ; 1	100.00	3/2	0.573 -0.687	9.524
	18	13.74	1^{+} ; 1	100.00	3/2	-3.995	11.783

a) These three excited states are 1p-shell forbidden in this reaction and excited via two-step processes .

b) This excited state is excited via indirect mechanism .

c) This excited state is not a 1p-shell state.

d) This excited state is excited via knock-out of a neutron from the p3/2-shell [15] .

FIGURE CAPTION

Fig. (1): Experimental (^{3}He, α) angular distributions for the 1/2-states ($^{15-19}$). [The incedent energies for the ^{3}He - projectile in the (^{3}He, α) - reactions on ^{9}Be, ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{14}N and ^{15}N nuclei are respectively 26.7, 33.7, 33.0, 35.65, 27.3, 25.4 and 39.8 Mev. The uncertainly of the cross - section is taken for all states to be ±10%. The solid curves smoothly connect the experimental points, this valid also for figures 2 - 6].

Fig. (2): Experimental (^{3}He,α) angular distributions for the 3/2-states ($^{15-19}$). See the caption of fig. (1).

Fig. (3): Experimental (^{3}He, α) angular distributions for the (5/2 or 7/2) - states (^{18}). See the caption of fig. (1).

Fig. (4): Comparison of the angular distributions of a state with J_{tr} (n) = 1/2 with another has J_{tr} (n) = 3/2 both have the same percentage or very nearly to show the differences between the forms of both curves. See the caption of fig. (1).

Fig. (5): The J - dependence for the 1/2 - states in the (^{3}He, α) - nuclear reactions on 1p - shell nuclei. They are plotted in the groups A, B and C according to their form. See the caption of fig. (1).

Fig. (6): The J - dependence for the 3/2 - states in the (^{3}He, α) - nuclear reactions on 1p - shell nuclei. They are plotted in the groups A, B, C and D according to their form. See the caption of fig. (1).

Fig. (7): Experimental ratios of the reaction cross - sections:

a) for the 3/2 - states 16.922, 17.64 and 19.07 MeV (states 3, 4 and 6 in table 1) to that of the 1/2 - state at 18.15 MeV (state number 5) of the nucleus ^8Be.

b) for the 3/2 - states 16.922 and 19.07 MeV (states 3 and 6 in table 1) to that of the 3/2 - state 17.64 MeV (state number 4) of the nucleus ^8Be. The uncertainty of the ratios is taken to be ±10% and in figures (8 - 12) is also the same as in this one.

Fig. (8): Experimental ratios of the reaction cross - section for the state 2.361 MeV to that of the g.s. both with J_{tr} (n) = 3/2 in the nucleus ^9B. See the caption of figure (7).

Fig. (9): Experimental ratios of the reaction cross - sections:

a) for the 3/2 - states g.s. 1.74, 2.154 and 4.774 MeV (states 0, 2, 3 and 5 in table 1) to that of the 1/2 - state at 0.718 MeV (state number 1) of the nucleus ^{10}B.

b) for the 3/2 states 1.74, 2.154 and 4.774 MeV (states 2, 3 and 5) to that of the 3/2 - state g.s. (state number 0) of the nucleus ^{10}B.

c) for the 1/2 - states 3.587 and 5.164 MeV (states 4 and 6) to that of the 1/2 state 0.718 MeV (state number 1) of the nucleus ^{10}B. See the caption of fig. (7).

Fig. (10): Experimental ratios of the reaction cross - sections:

a) for the 3/2 - states g.s., 4.804 and 8.104 MeV (states 0, 3 and 5 in table 1) to that of the 1/2 - state at 2.00 MeV (state number 1) of the nucleus ^{11}C.

b) for the 3/2 - states 4.804 and 8.104 MeV (states 3 and 5) to that of the 3/2 - state g.s. (state number 0) of the nucleus ^{11}C.

c) for the states 6.478 and 8.420 MeV (states 4 and 6) with J_{tr} (n) = 7/2 and 5/2 respectively to that of the 5/2 - state 4.319 MeV of the nucleus ^{11}C [all these three states have L_{tr} (n) = 3]. See the caption of fig. (7).

Fig. (11): Experimental ratios of the reaction cross - sections:

a) for the 3/2 - states 4.439, 12.710, 15.11 and 16.106 MeV (states 1, 3, 4 and table 1) to that of the 1/2 - state g.s. (state number 0) of the nucleus ^{12}C.

b) for the 3/2 - states 15.11 and 16.106 MeV (states 4 and 5) to that of the 3/2 - state 12.71 MeV (state number 3) of the nucleus ^{12}C.

c) for the 1/2 - state 7.654 MeV (state number 2) to that of the 1/2- state g.s. (state number 0) of the nucleus ^{12}C. See the caption of fig. (7).

Fig. (12): Experimental ratios of the reaction cross - sections:

a) for the 3/2 - states 3.945, 7.029, (9.172 + 10.432) and 13.74 MeV (states 2, 3, 6 and 18 in table 1) to that of the 1/2 - state g.s. (state number 0) of the nucleus ^{14}N.

b) for the 3/2 - states 7.029, (9.172 + 10.432) and 13.74 MeV (states 3, 6 and 18) to that of the 3/2 - state 3.945 MeV (state number 2) of the nucleus ^{14}N.

c) for the 1/2 - state 2.313 MeV (state number 1) to that of the 1/2- state g.s. (state number 0) of the nucleus ^{14}N. See the caption of fig. (7).

خلاصة

البراهين العلمية للإعتماد على كمية الحركة الزاوية الكلية المحمولة فى تفاعلات (^{3}He, α) على أنوية القشرة -1P

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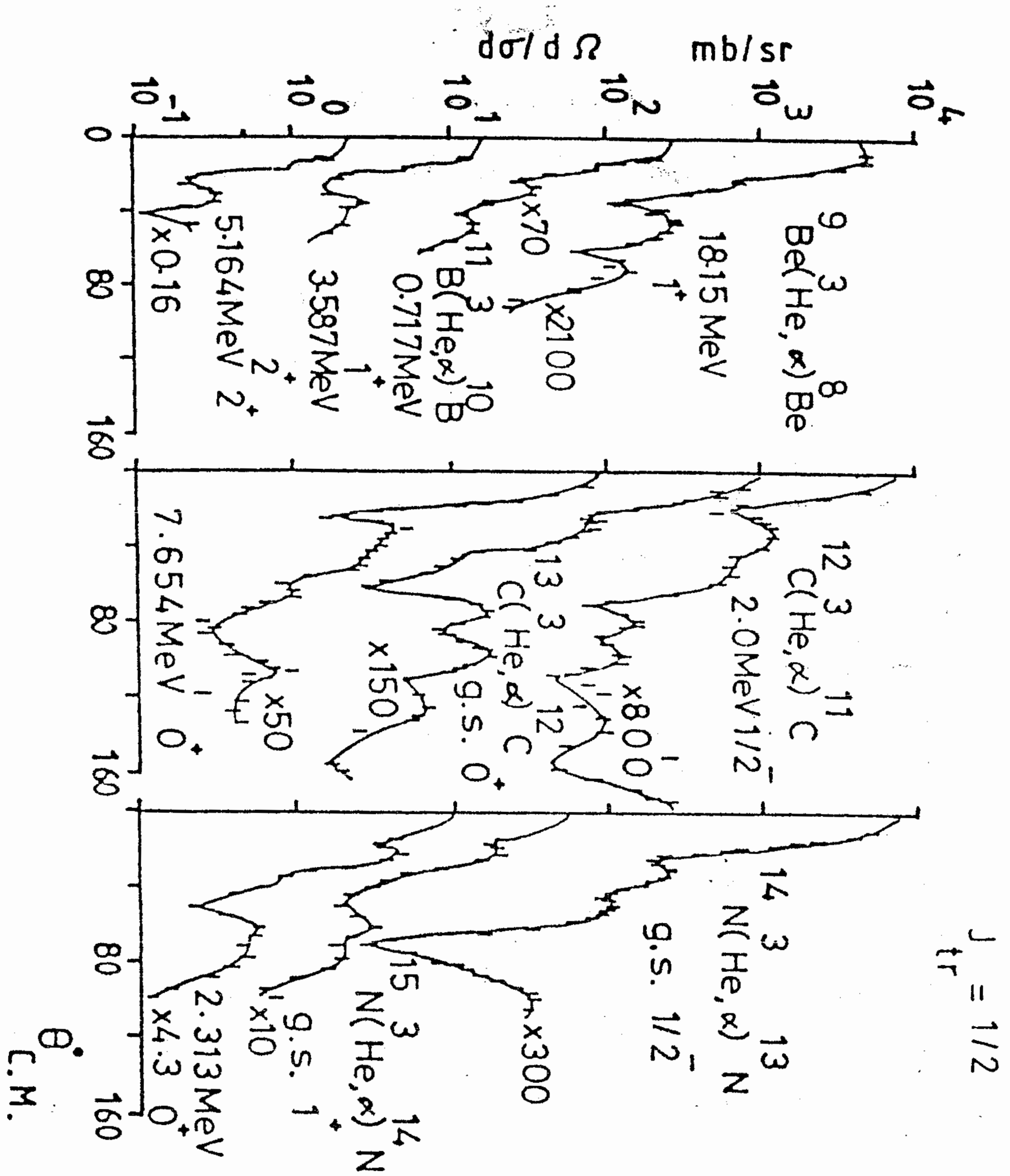
يقوم هذا البحث على إستخدام النتائج العملية لعدد من الباحثين لتفاعل (^{3}He, α) على أنوية القشرة – 1P عن طاقة سقوط للهيليوم – ٣ قيمتها المتوسطة هى ٣١ م. أ. ف. لدراسة إعتماد أشكال التوزيعات الزاوية التجريبية لمستويات الطاقة المناظرة على كمية الحركة الزاوية المحمولة. ولقد إستخدمت فى دراسة تلك الظاهرة طريقتان. الطريقة الأولى تعتمد على مقارنة أشكال التوزيعات الزاوية لمستويات الطاقة للأنوية المختلفة التى لها نفس كمية الحركة الزاوية الكلية المحمولة. أما الطريقة الثانية فأنها تعتمد على مقارنة المنحنيات التجريبية لنسب أحتمالية حدوث التفاعل (Experimental cross - section ratio curves) لمستويات الطاقة المختلفة لكل نواه على حده التى لها كمية حركة زاوية كلية محمولة واحدة. لقد أمكن من خلال هاتين الطريقتين الوصول إلى حقيقة أن أشكال التوزيعات الزاوية الخاصة بهذا التفاعل تعتمد فيما بينها على كمية الحركة الزاوية الكلية المحمولة خلال التفاعل. وقد تبين أن النتائج المستخلصة من هذا البحث تتفق مع ما سبقها من نتائج عملية وكذلك مع ما تنبأ به نظرياً.


dσ/dΩ mb/sr
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10^3
10^2
10^1
10^0
10^-1
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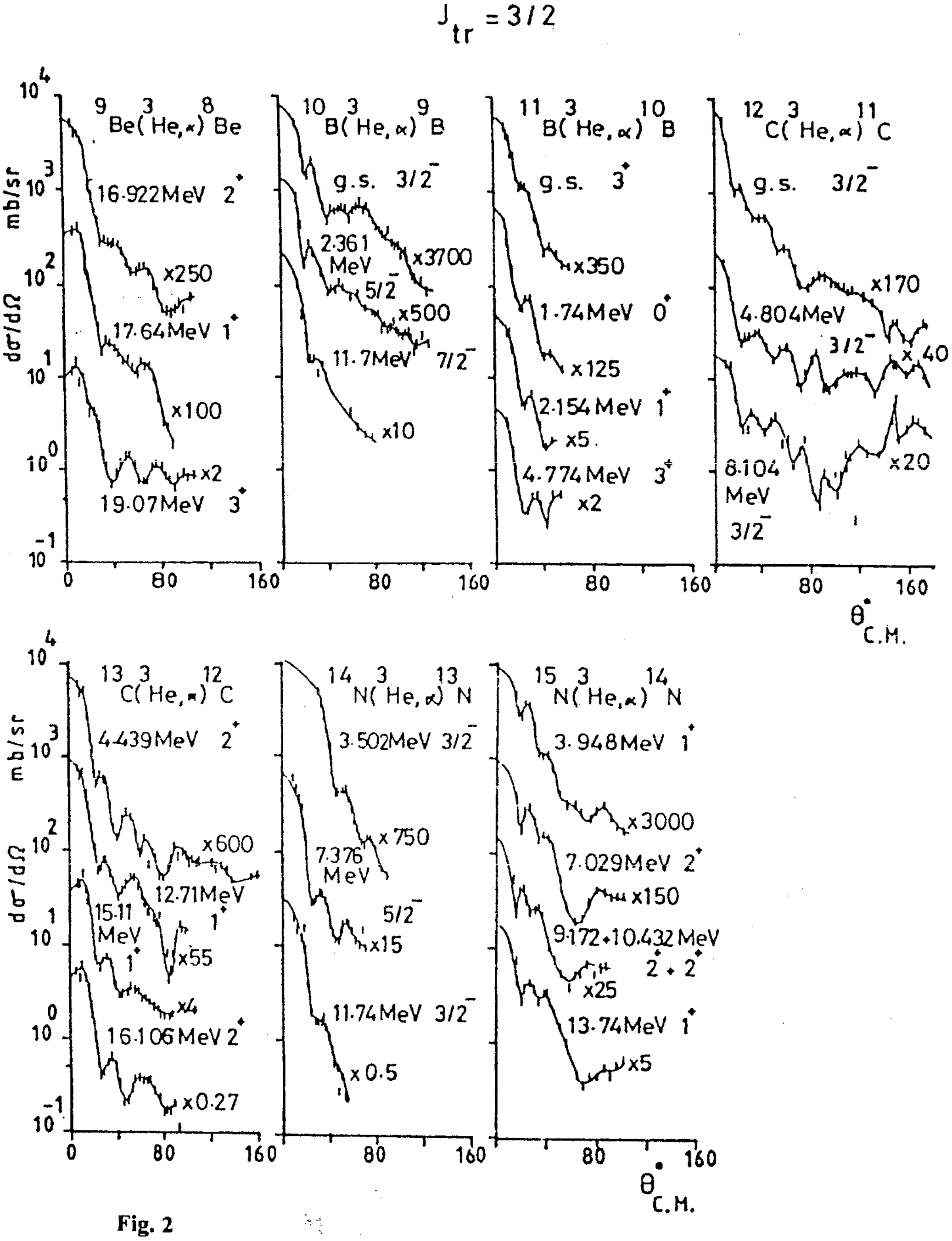
80
160
9Be(3He,α)8Be
18.15 MeV
1+
x2100
x70
11B(3He,α)10B
0.717 MeV
1+
3.587 MeV
1+
5.164 MeV 2+ 2+
x0.16
12C(3He,α)11C
2.0 MeV 1/2-
x800
13C(3He,α)12C
g.s. 0+
x150
7.654 MeV 0+
x50
14N(3He,α)13N
g.s. 1/2-
x300
15N(3He,α)14N
g.s. 1+
x10
2.313 MeV 0+
x4.3
J_tr = 1/2
θ° C.M.

Fig. 1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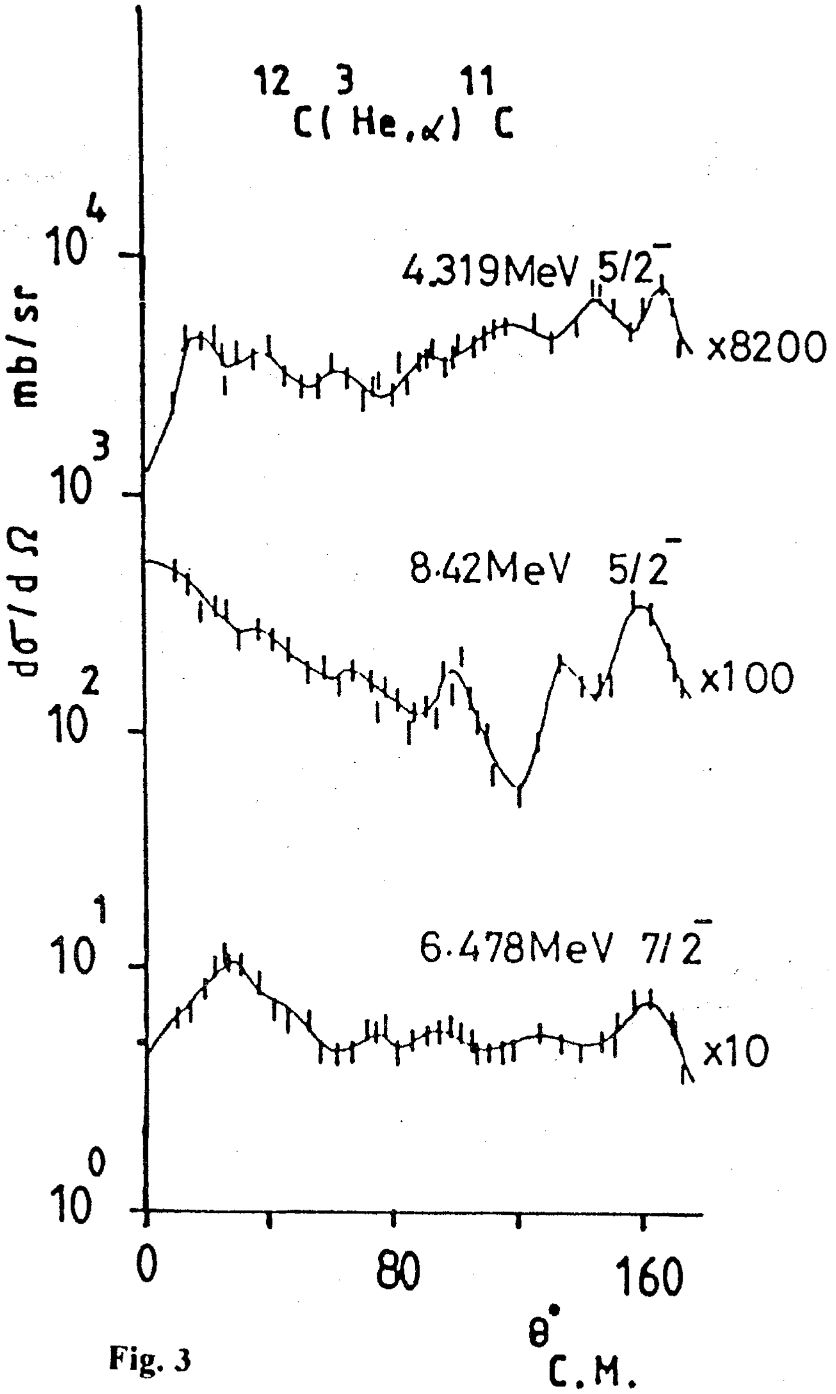
x250
17.64MeV 1+
x100
x2
19.07MeV 3+
$^{10}B(^3He,\alpha)^9B$
g.s. 3/2−
2.361 MeV 5/2−
x3700
x500
11.7MeV 7/2−
x10
$^{11}B(^3He,\alpha)^{10}B$
g.s. 3+
x350
1.74MeV 0+
x125
2.154MeV 1+
x5
4.774MeV 3+
x2
$^{12}C(^3He,\alpha)^{11}C$
g.s. 3/2−
x170
4.804MeV 3/2−
x40
8.104 MeV 3/2−
x20
$^{13}C(^3He,\alpha)^{12}C$
4.439MeV 2+
x600
12.71MeV 1+
15.11 MeV 1+
x55
x4
16.106MeV 2+
x0.27
$^{14}N(^3He,\alpha)^{13}N$
3.502MeV 3/2−
x750
7.376 MeV 5/2−
x15
11.74MeV 3/2−
x0.5
$^{15}N(^3He,\alpha)^{14}N$
3.948MeV 1+
x3000
7.029MeV 2+
x150
9.172+10.432MeV 2+ + 2+
x25
13.74MeV 1+
x5
dσ/dΩ mb/sr
10^4
10^3
10^2
10^1
10^0
10^{-1}
0
80
160
$\theta^\circ_{C.M.}$

Fig. 2


12 3 11
C(He,α) C
dσ/dΩ mb/sr
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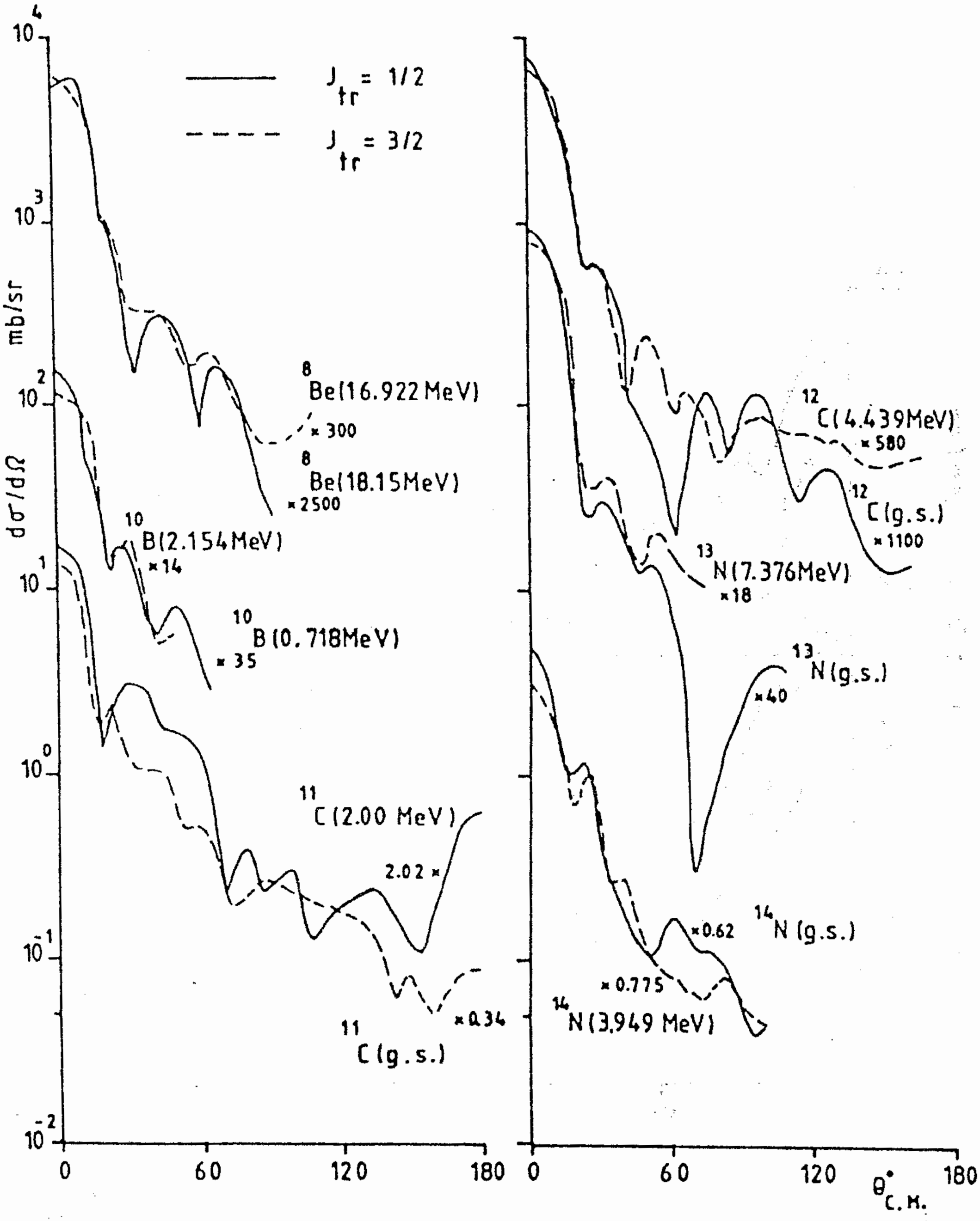
10^3
10^2
10^1
10^0
4.319MeV 5/2⁻
x8200
8.42MeV 5/2⁻
x100
6.478MeV 7/2⁻
x10
0
80
160
θ°
C.M.

Fig. 3


$J_{tr} = 1/2$
$J_{tr} = 3/2$
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10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
dσ/dΩ mb/sr
^{8}Be(16.922 MeV)
× 300
^{8}Be(18.15 MeV)
× 2500
^{10}B(2.154 MeV)
× 14
^{10}B(0.718 MeV)
× 35
^{11}C(2.00 MeV)
2.02 ×
× 0.34
^{11}C(g.s.)
^{12}C(4.439 MeV)
× 580
^{12}C(g.s.)
× 1100
^{13}N(7.376 MeV)
× 18
^{13}N(g.s.)
× 40
× 0.62
^{14}N(g.s.)
× 0.775
^{14}N(3.949 MeV)
0
60
120
180
0
60
120
180
$\theta^\circ_{c.m.}$

Fig. 4

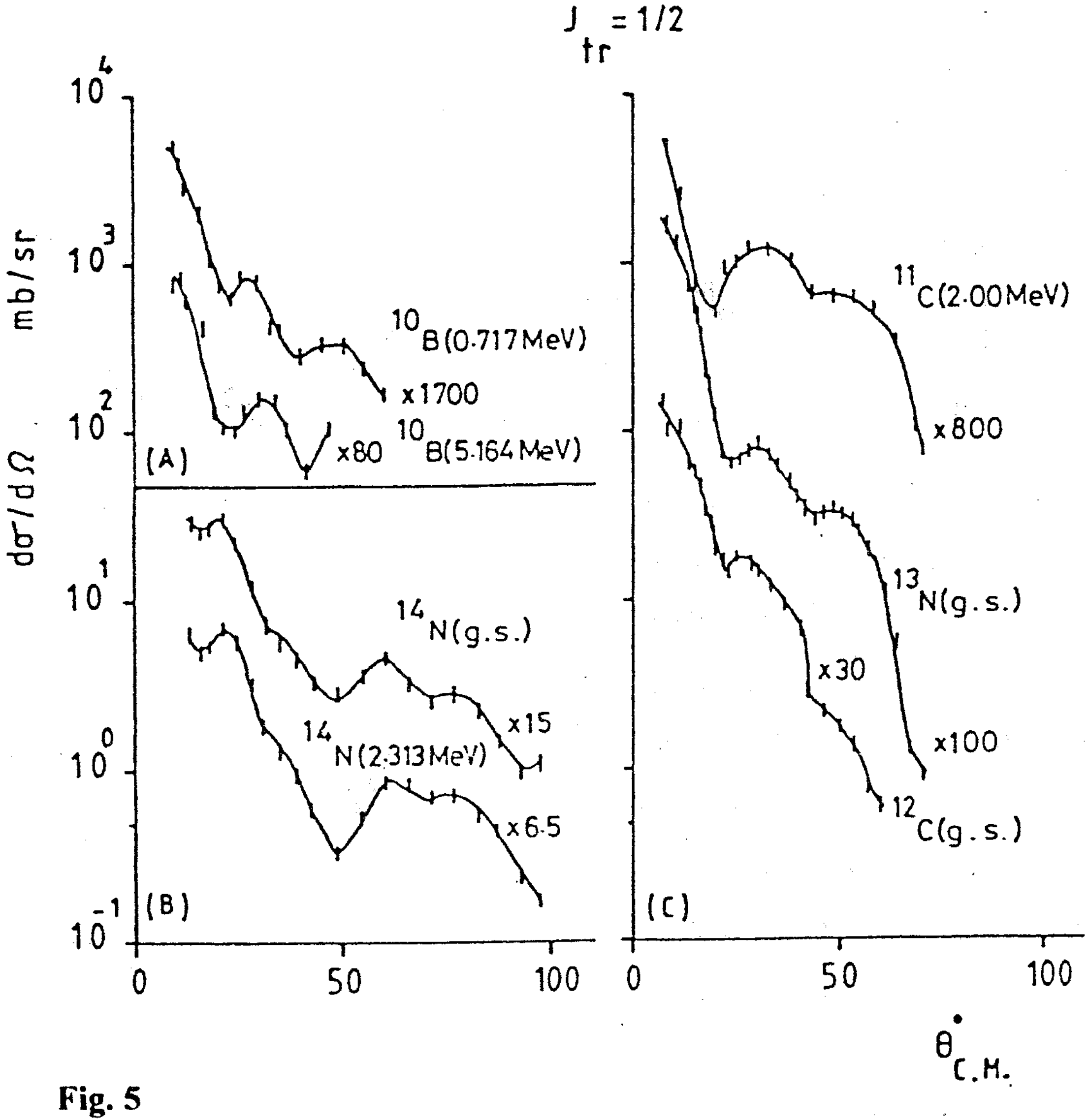

J$_{tr}$ = 1/2
dσ/dΩ mb/sr
10^4
10^3
10^2
10^1
10^0
10^{-1}
(A)
(B)
(C)
^{10}B(0.717MeV)
x1700
^{10}B(5.164MeV)
x80
^{14}N(g.s.)
x15
^{14}N(2.313MeV)
x6.5
^{11}C(2.00MeV)
x800
^{13}N(g.s.)
x100
^{12}C(g.s.)
x30
0
50
100
θ°$_{C.M.}$

Fig. 5

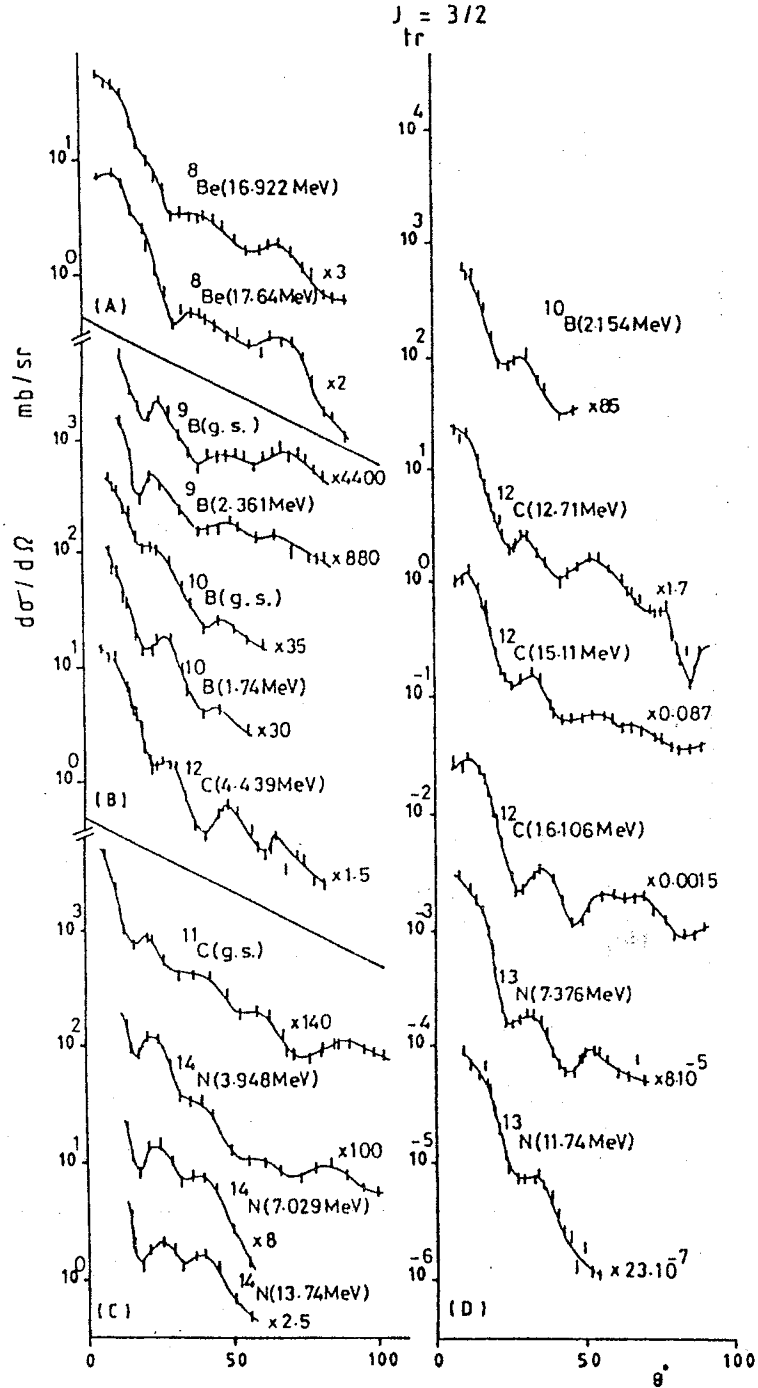

J_tr = 3/2
dσ/dΩ mb/sr
8Be(16.922 MeV)
x3
8Be(17.64MeV)
x2
(A)
9B(g. s.)
x4400
9B(2.361MeV)
x880
10B(g.s.)
x35
10B(1.74MeV)
x30
12C(4.439MeV)
x1.5
(B)
11C(g.s.)
x140
14N(3.948MeV)
x100
14N(7.029MeV)
x8
14N(13.74MeV)
x2.5
(C)
10B(2.154MeV)
x85
12C(12.71MeV)
x1.7
12C(15.11MeV)
x0.087
12C(16.106MeV)
x0.0015
13N(7.376MeV)
x8.10^-5
13N(11.74MeV)
x23.10^-7
(D)
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
0
50
100
θ°C.M.

Fig. 6

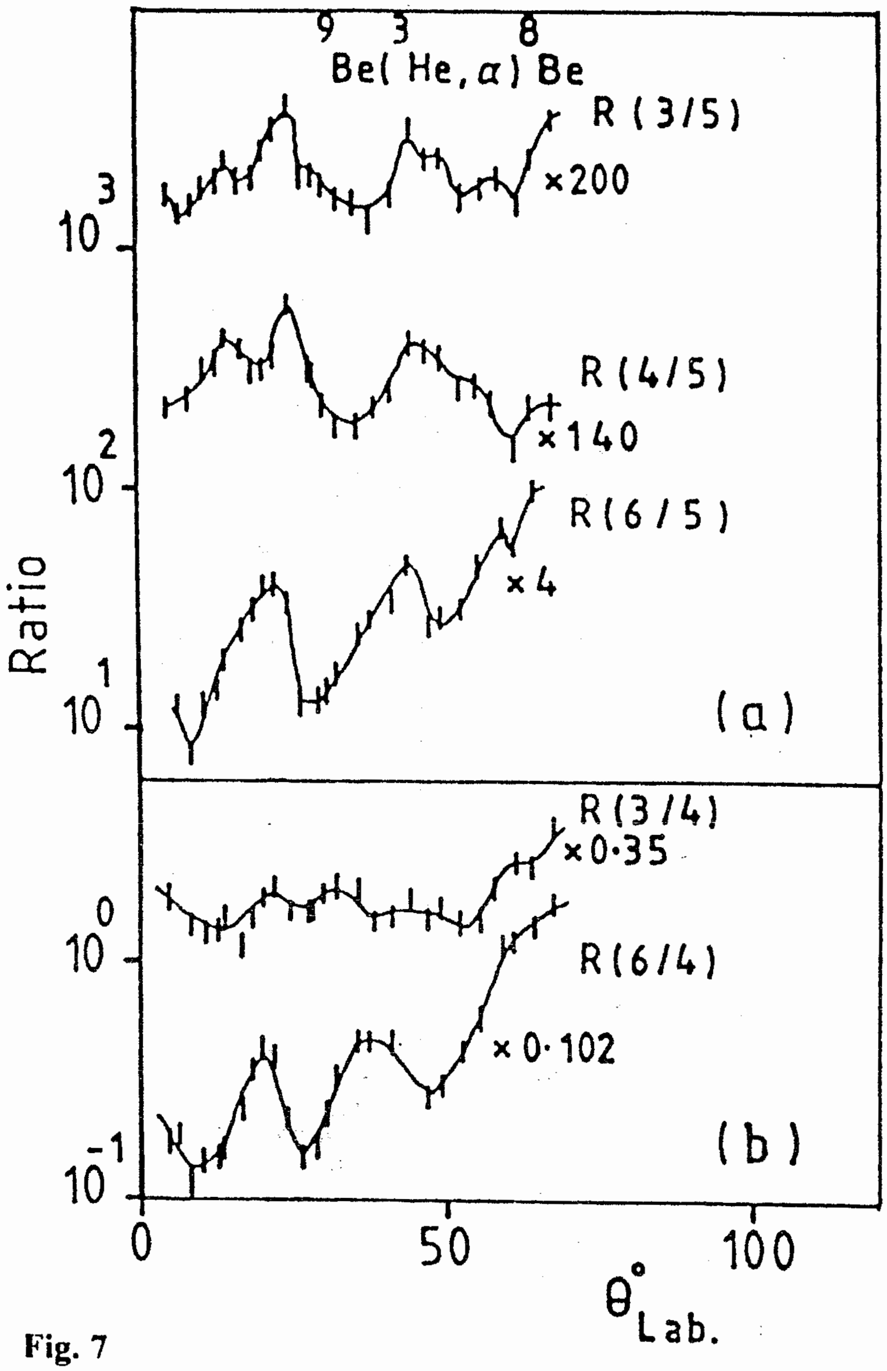

^{9}Be(^{3}He,α)^{8}Be
R(3/5)
×200
R(4/5)
×140
R(6/5)
×4
(a)
R(3/4)
×0·35
R(6/4)
×0·102
(b)
Ratio
10^3
10^2
10^1
10^0
10^{-1}
0
50
100
θ°Lab.

Fig. 7

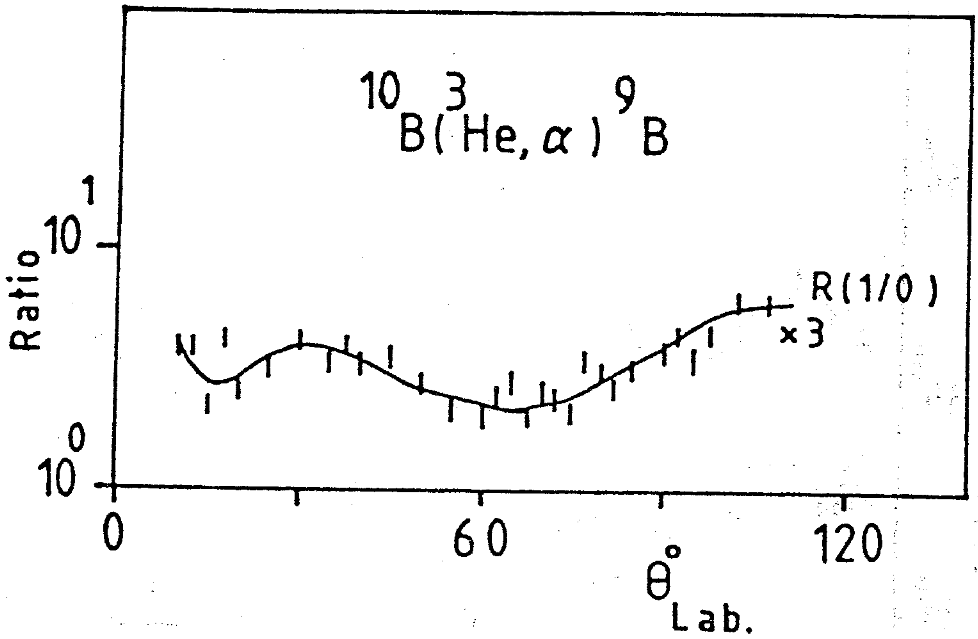


Fig. 8

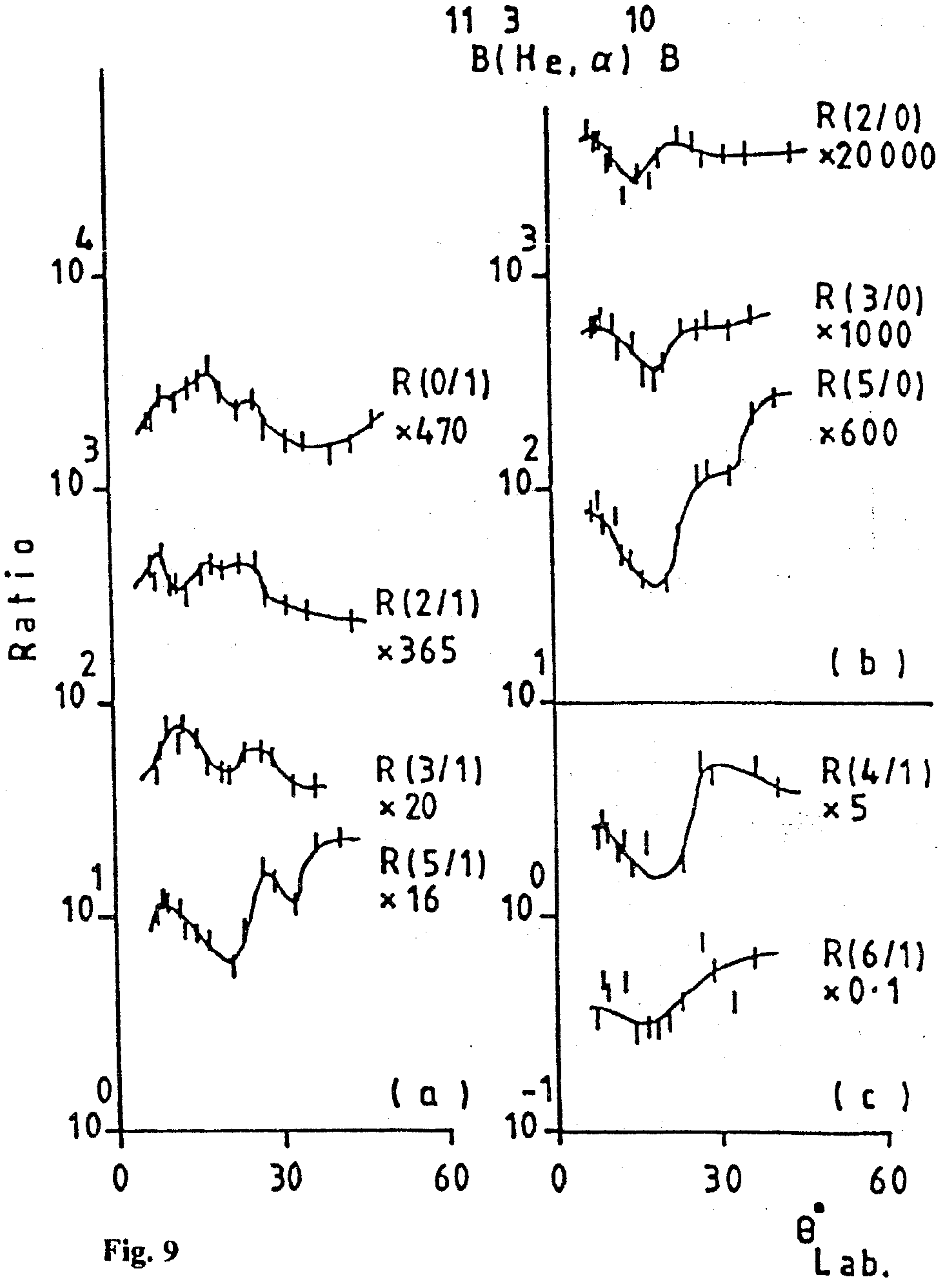
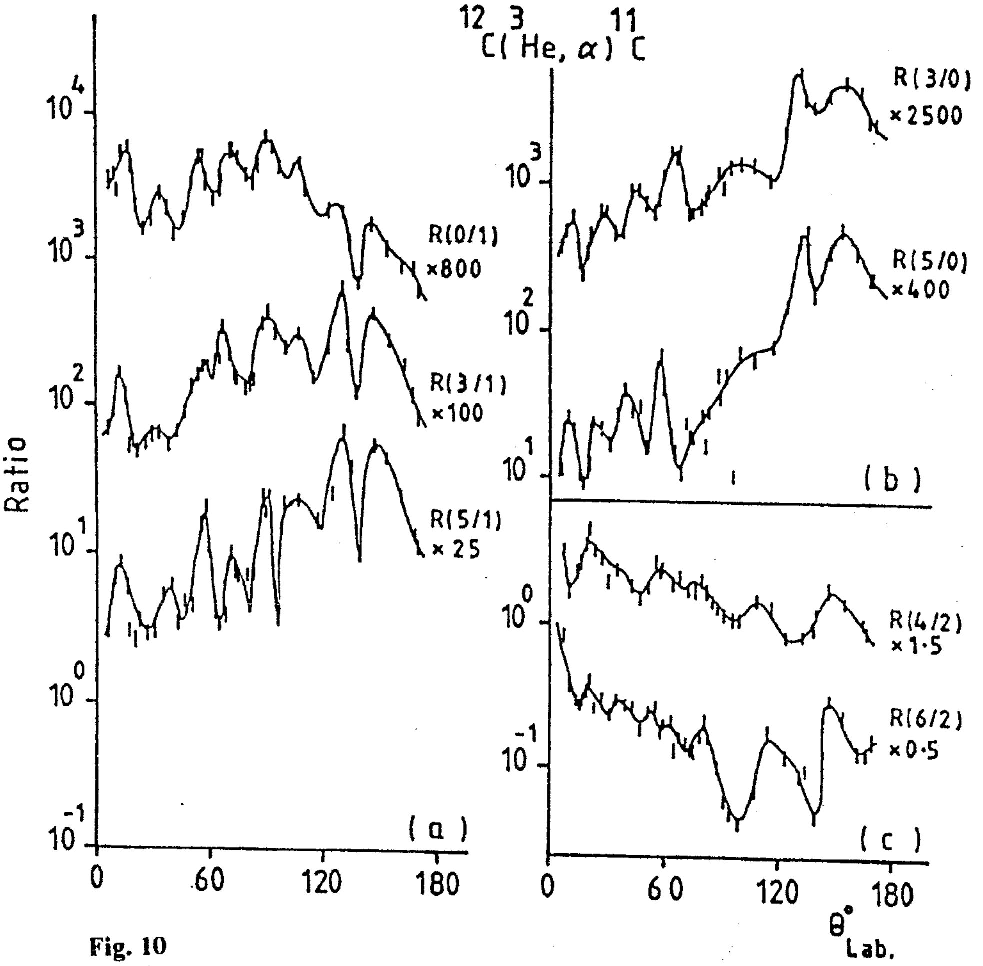

$^{11}B(^3He,\alpha)^{10}B$
Ratio
10^4
10^3
10^2
10^1
10^0
R(0/1) ×470
R(2/1) ×365
R(3/1) × 20
R(5/1) × 16
(a)
R(2/0) ×20000
R(3/0) ×1000
R(5/0) ×600
(b)
R(4/1) × 5
R(6/1) × 0·1
(c)
10^{-1}
0
30
60
θ° Lab.

Fig. 9



$^{12}C(^{3}He,\alpha)^{11}C$
Ratio
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
R(0/1) ×800
R(3/1) ×100
R(5/1) × 25
(a)
0
60
120
180
R(3/0) ×2500
R(5/0) ×400
(b)
R(4/2) ×1·5
R(6/2) ×0·5
(c)
$\theta^{\circ}_{Lab.}$

Fig. 10

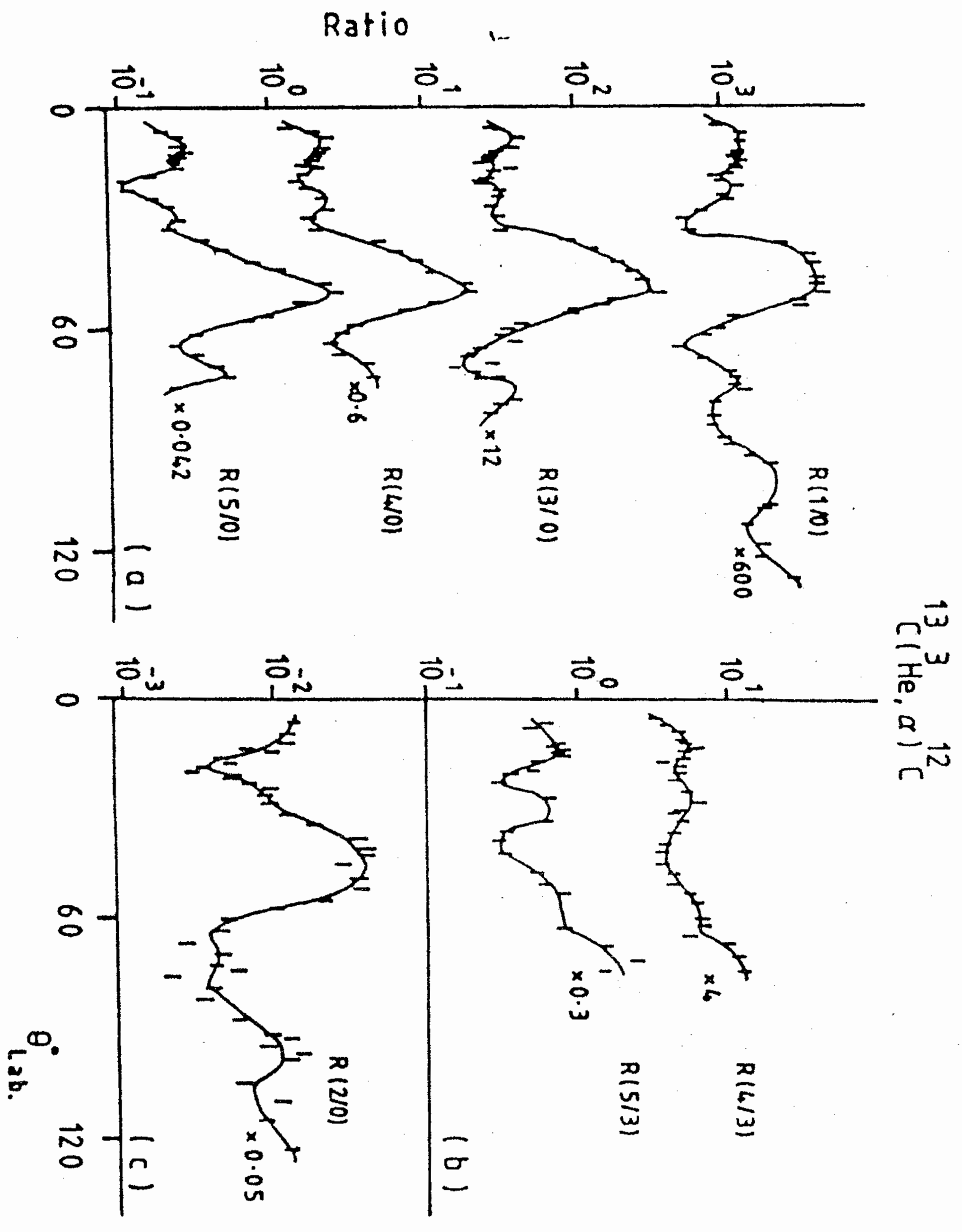

Ratio
10^3
10^2
10^1
10^0
10^-1
0
60
120
R(1/0)
×600
R(3/0)
×12
R(4/0)
×0·6
R(5/0)
×0·042
(a)
13C(3He,α)12C
10^1
10^0
10^-1
R(4/3)
×4
R(5/3)
×0·3
(b)
10^-2
10^-3
R(2/0)
×0·05
(c)
θ°Lab.

Fig. 11

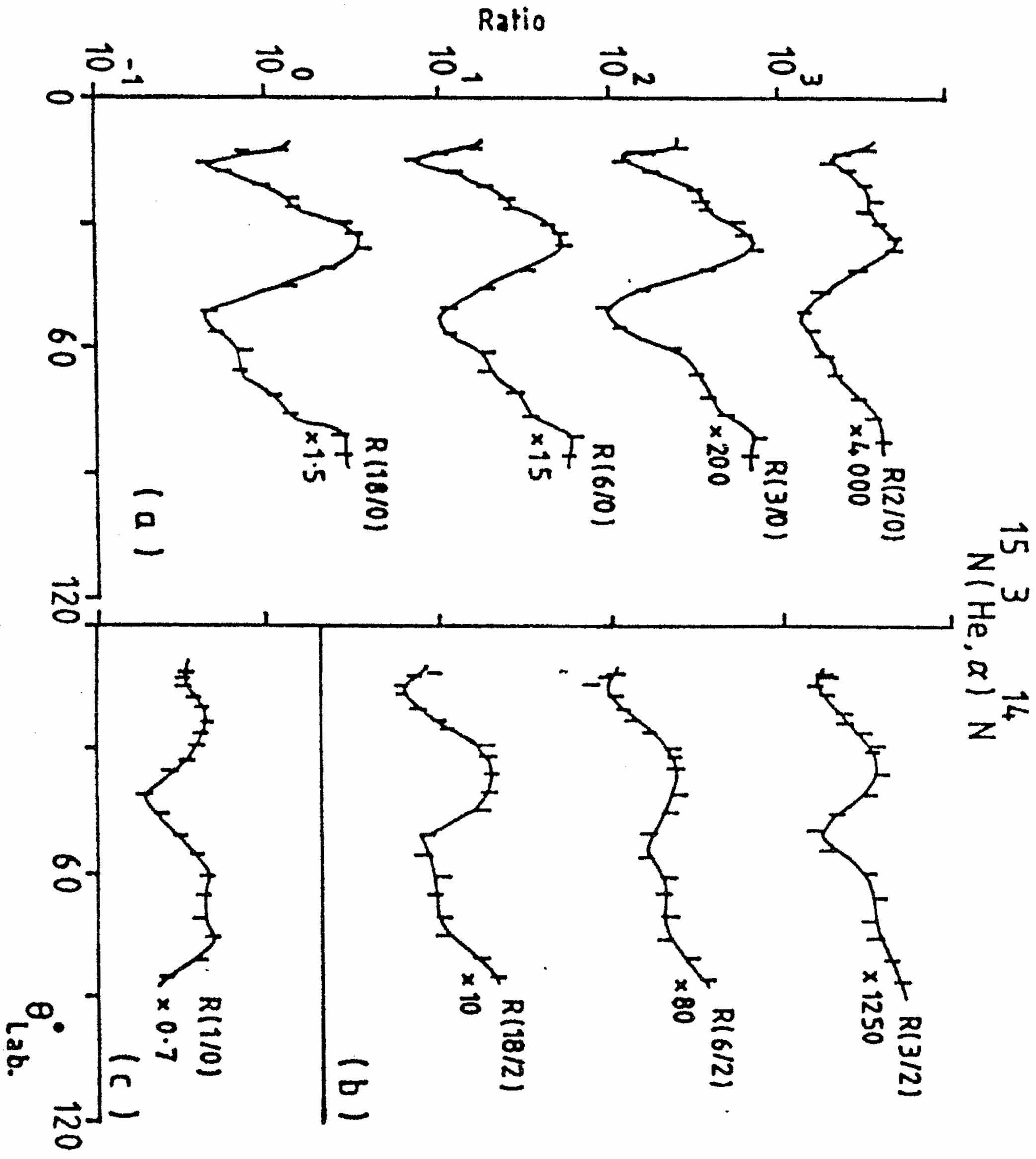

Ratio
10^-1
10^0
10^1
10^2
10^3
0
60
120
θ° Lab.
15N(3He,α)14N
R(2/0) ×4000
R(3/0) ×200
R(6/0) ×15
R(18/0) ×1.5
(a)
R(3/2) ×1250
R(6/2) ×80
R(18/2) ×10
(b)
R(1/0) ×0.7
(c)

Fig. 12