FIZIKA, 5 (1973) 103–112

J FORBIDNESS OF COMPOUND NUCLEUS MECHANISM IN THE CASE OF $^{9}Be + {}^{3}He$ REACTIONS AT LOW ENERGY

K. M. SUBOTIĆ, D. M. STANOJEVIĆ, M. R. ALEKSIĆ and B. Z STEPANČIĆ

Institute of nuclear sciences »Boris Kidrič«, Beograd

and

R. V. POPIĆ

Faculty of Natural Sciences, Beograd and Institute of nuclear sciences

»Boris Kidrič«, Beograd

Received 1 March 1973

Abstract: $^{9}Be(^{3}He, n)^{11}C$, $^{9}Be(^{3}He, n\gamma)^{11}C$, $^{9}Be(^{3}He, p\gamma)^{11}B$ and $^{9}He(^{3}Be, p)^{11}B$ reactions are studied, at 500 keV $< E_{^{3}He} <$ 1100 keV, in an attempt to obtain the additional data on 26. 9 MeV level of ^{12}C. The absence of any resonant behaviour at excitations corresponding to 26. 9 MeV in ^{12}C system is interpreted as a case of J forbidness of compound nucleus mechanism, J^{π} being limited to 0^{-}, 3^{-} and 4^{-} for this state. This forbidness inaugurates the direct mechanisms to be dominant even at low energy, as seen from the fits of experimental data.

1. Introduction

The studies[1, 2, 3] of $^{11}B(p, \gamma)^{12}C$ and $^{11}B(p, \alpha)^{8}Be$ reactions have revealed, amongst other data, the existence of a resonance corresponding to a level of ^{12}C at the excitation of 26.9 MeV. However, the spin and parity of this state was derived in very broad experimental limits, i. e. $0^{-} \leq J^{1} \leq 4^{-}$ or $0^{+} \leq J^{\pi} \leq 3^{+}$, incorpo-

rating therefore $J^{\pi} = 3^{-}$, which was predicted theoretically[4]. We report here the study of $^{9}Be + {}^{3}He$ reactions, which was undertaken with the aim to give additional data on 26.9 MeV level in ^{12}C and to indicate the reaction mechanism at low energy.

Three experiments are reported here. First one, leading to the determination of excitation function of $^{9}Be(^{3}He, p, \gamma)^{11}B$ and $^{9}Be(^{3}He, n\gamma)^{11}C$ reactions, by measurement of gamma spectra. Second, leading to the determination of excitation function od $^{9}Be(^{3}He, p)^{11}B$ reaction by measurement of ten proton groups yields; the determination of angular distributions was done also. Third, leading to the determination of excitation function of $^{9}Be(^{3}He, n)^{11}C$ reaction by measurement of β^{+} activity of the final nucleus ^{11}C.

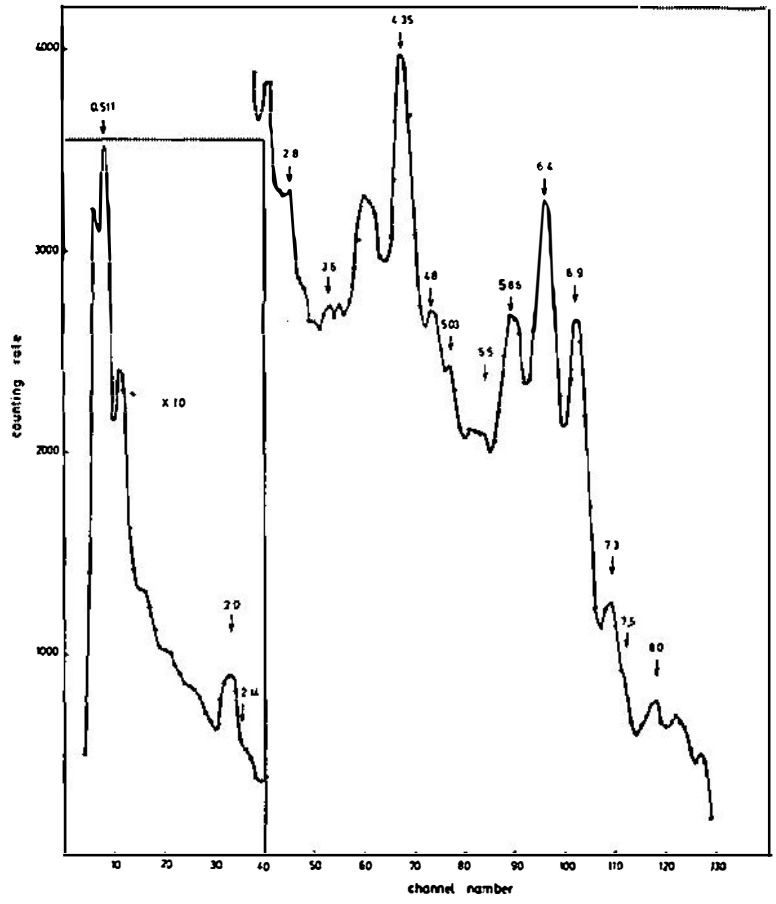

Fig. 1. Gamma ray spectrum from $^{9}Be + {}^{3}He$ reactions. Numbers above the peaks are gamma ray energies in MeV.

2. *Experimental methods and results*

The ^{3}He-beam of the 1.5 MeV Cockcroft-Walton accelerator of the »Boris Kidrič« Institute was analysed by an electrostatic analyser, defining the beam energy to $\pm$ 3 keV. The ^{3}He current at the target, which was placed in all runs at the centre of the scattering chamber, was typically about 0.1 μA. Intensity of the beam was always controlled by a current integrator. The targets were 30 $\pm$ 10 μg/cm^2 thick Be evaporated on the nickel backing. The thickness of the target was determined using (p, γ) reaction on ^{9}Be around known resonance at E_p = 1080 keV by measuring its experimental width. In all runs the pulses from the counter were fed, after amplification, to a 256-channel pulse-height analyser.

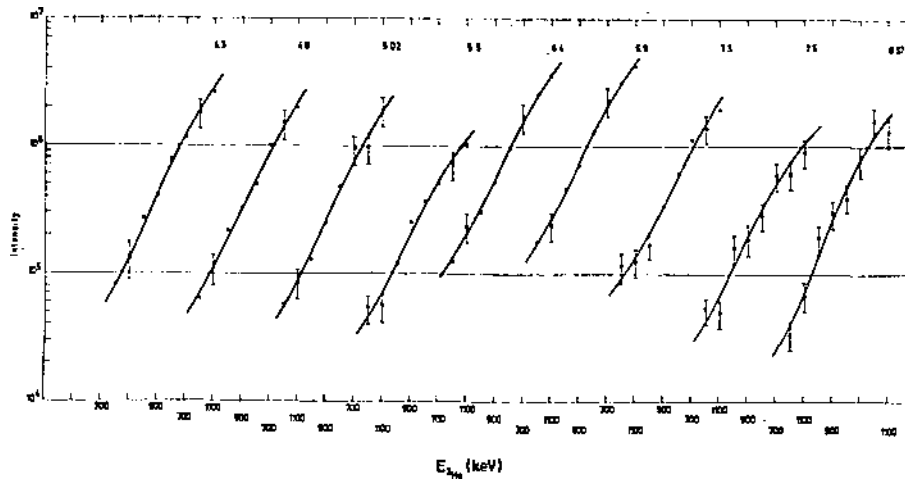

Fig. 2. Excitation functions of gamma rays from ^{9}Be + ^{3}He reactions.

^{9}Be(^{3}He, pγ)^{11}B and ^{9}Be(^{3}He, n γ)^{11}C experiment. Gamma rays from ^{9}Be+^{3}He reactions were detected by a 5″ × 6″ NaI(Tl) scintillation counter. This counter was calibrated using a set of IAEA gamma sources for low energy, and ^{24}Na decay and ^{19}F(p, $\alpha\gamma$)^{16}O reaction for higher energy part of the spectrum. Between the target and the face of NaI(Tl) crystal there was a solid angle of $\pi/6$ sr.

The gamma spectra were taken, for $E_{^3He}$ ranging from 0.750 to 1.100 MeV, in steps of 50 keV. A typical spectrum (for $E_{^3He}$ = 1.100 MeV) is given in Fig. 1. The compositional analysis of each spectrum was performed using a standard procedure based on fitting the shape of gamma lines (obtained on basis of calibration) and their »tails« to the experimental gamma lines, starting this step-by-step procedure

at the highest energy peak and subtracting one-by-one partial gamma line form. This was done for $4.3 < E_\gamma < 9.0$ MeV since the yield above 9.0 MeV was negligible and at energies lower then 4.3 MeV a strong neutron background made the analysis practically meaningless. The error in the determination was 17% for the strongest ones and going up to 30% for the weakest determined intensities. The yields of these gamma rays, intensities of which were determined in such way, are given, in function of energy, in Fig. 2.

$^9Be(^3He, p)^{11}B$ experiment. The experiment was performed in a scattering chamber, in which a 2 mm thick silicon counter was used to detect protons up to $E_p = 12$ MeV. The elastically scattered ^{3}He ions were stopped by Al foil placed in the front of detector. A typical proton spectrum, taken at $R_{^3He} = 0.820$ MeV

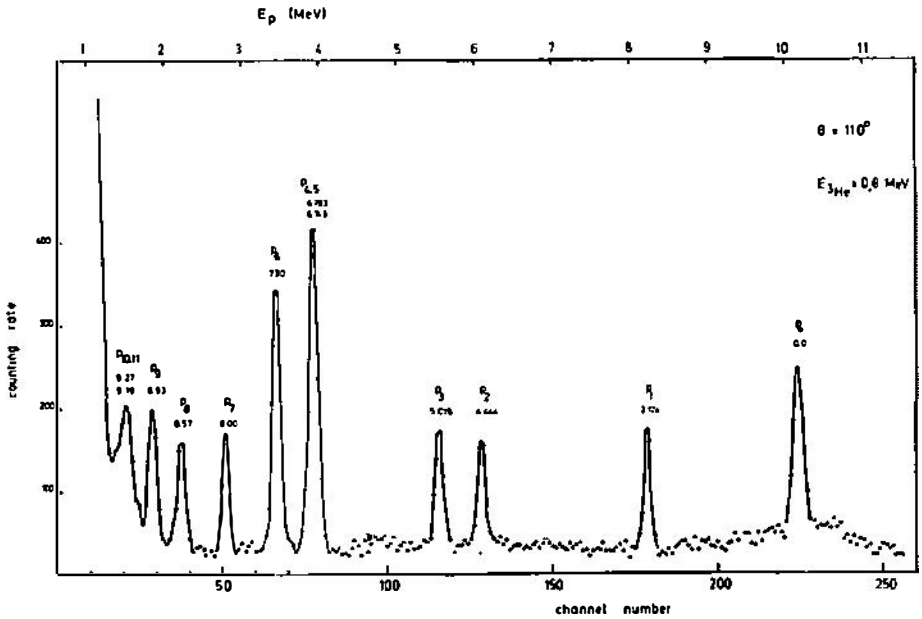

Fig. 3. Spectrum of the protons from the ^{9}Be(^{3}He, p)^{11}B reaction. Numbers above the peaks are the excitation energies of the final nucleus.

and $\Theta_p = 110°$, is given in Fig. 3. All proton groups are easily resolved except p_4 and p_5 corresponding to the states of ^{11}B at 6.743 MeV and 6.793 MeV. As seen from Fig. 3. other reaction did not interfere in the studied part of the spectrum.

In the ^{3}He energy range from 0.500 to 1.100 MeV, the yields of ten proton groups were determined at $\Theta_p = 110°$. These results are given in Fig. 4 and it is to be noted that the normalization was done to the cross-section measured at 1.000 MeV by W. R. Cokker et al.[5].

The angular distributions were measured at 0.820 MeV and 1.100 MeV in steps of 10°, from 0° to 150°. In Fig. 5 and 6. these results are given for $p_0 - p_9$ groups

(except unresolved p_4 and p_5) at 0.820 MeV and in Fig. 7. for $p_0 - p_3$ groups at 1.100 MeV.

$^9Be(^3He, n)^{11}C$ experiment. The total cross section of ^{9}Be(^{3}He, n)^{11}C reaction was determined by measuring activity of ^{11}C after each ^{3}He irradiation. Since the half-life of ^{11}C is 20.39 min, each irradiation was 15 min long and the annihilation

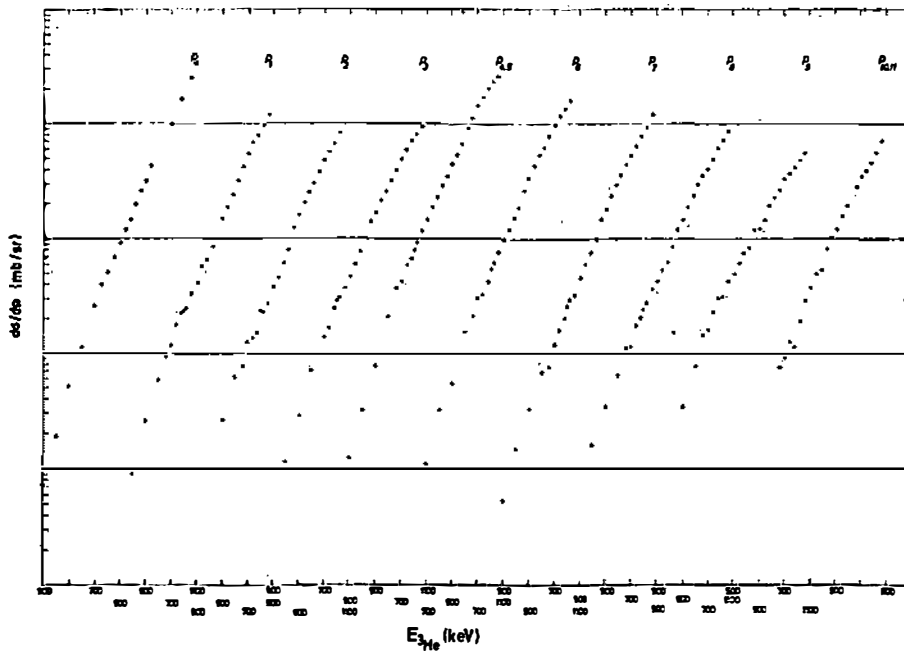

Fig. 4. Excitation functions of the protons, at $\Theta = 110°$, from the ^{9}Be(^{3}He, p)^{11}B reaction

gamma rays, discriminated by a window at 511 keV, were measured by scintillation counter intervals of 10 min for 100 min totally. The cross-section, in the energy range from 0.600 to 1.150 MeV, is presented in Fig. 8.

3. *Discussion*

It is seen from Fig. 2, 4 and 8 that the excitation functions of all nine exit channels measured in first experiment, all ten exit channels measured in the second experiment and those involved in the third experiment, did not show any sign of resonance behaviour in the measured energy region. Therefore, we state that 26.9 MeV level of ^{12}C is not formed via ^{9}Be + ^{3}He channel. In order to re-check this statement we tried also to divide one-by-one of our curves by energy very dependent product of Coulomb penetrabilities of input and exit channels, looking namely for a quantity

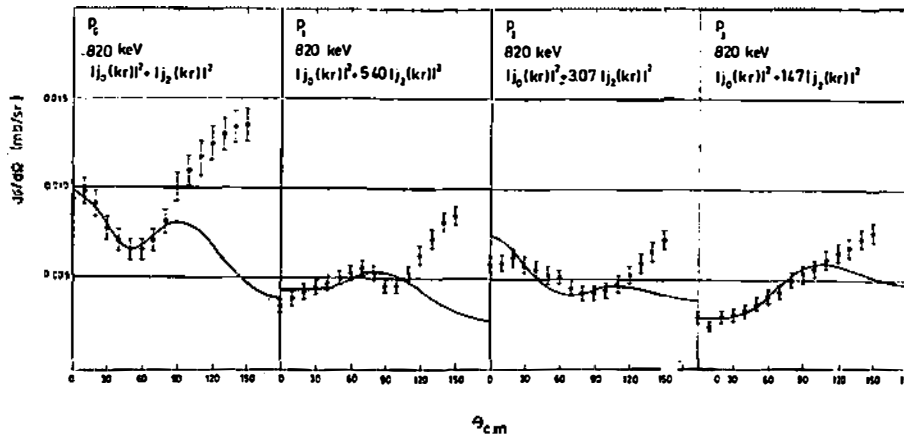

Fig. 5. Angular distributions of the p_0, p_1, p_2 and p_3 groups at 820 keV ^{3}He energy. Solid line is the theoretical curve for two-particle stripping.

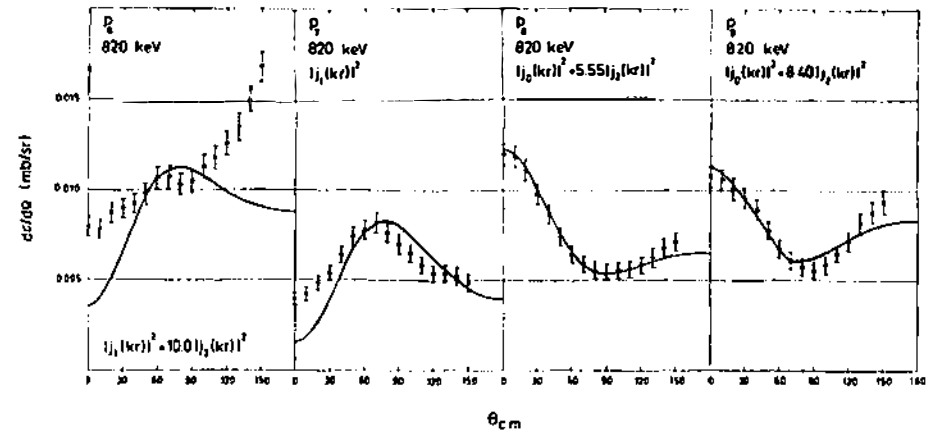

Fig. 6. Angular distributions of the p_6, p_7, p_8 and p_9 groups at 820 keV ^{3}He energy. Solid line is the theoretical curve for two-particle stripping.

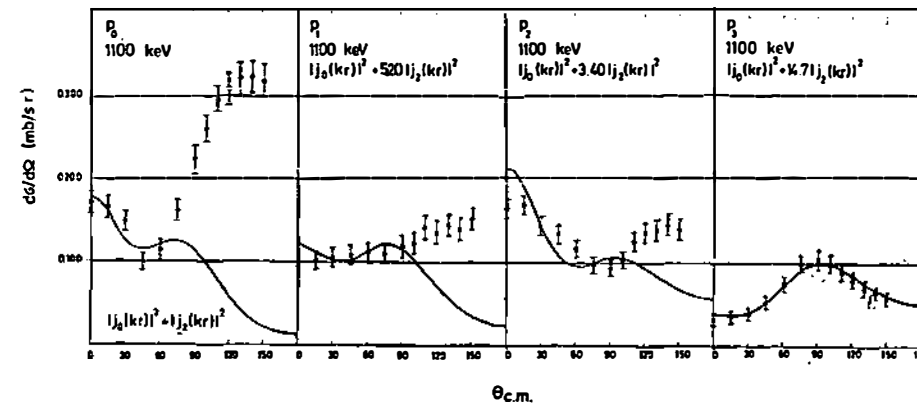

Fig. 7. Angular distributions of the p_0, p_1, p_2 and p_3 groups at 1100 keV ^{3}He energy. Solid line is the theoretical curve for two-particle stripping.

$$A = \frac{N_{exp}}{4 \frac{k_{out}}{k_{in}} P_{l_{in}} P_{l_{out}}}$$

which showed to be useful in our earlier work[6]. This, however, did not change our basic statement in this case.

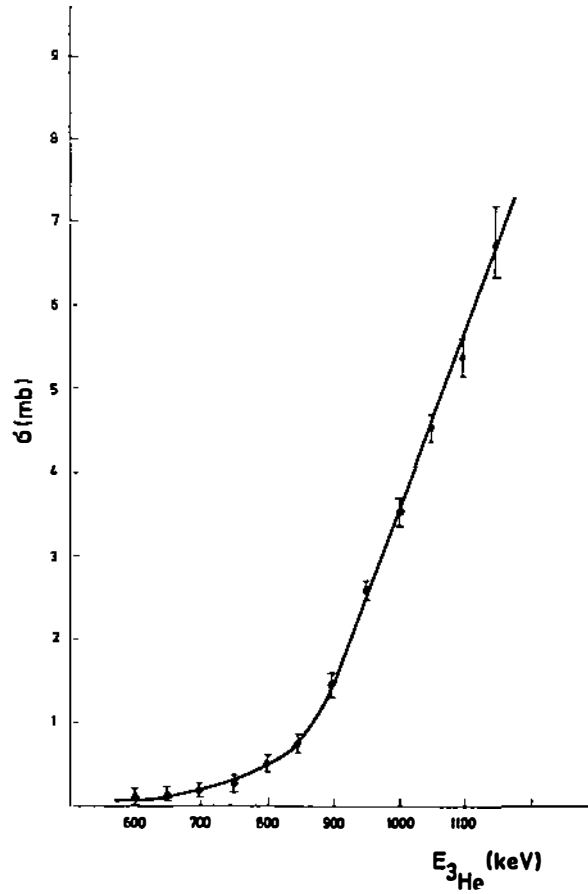

Fig. 8. Energy dependence of total cross-section for $^{9}Be(^{3}He, n)^{11}C$ reaction.

We are, thus, faced with the facts that $^{11}B + p$ channel forms 26.9 MeV level and $^{9}Be + {}^{3}He$ channel does not. The explanation of these facts goes as follows:

— $^{11}Be + p$ channel at energy corresponding to 26.9 MeV of ^{12}C (laboratory proton energy 11.37 MeV) is open to all values of spin and parity in limits $0^- \leq \leq J^\pi \leq 4^-$ and $0^+ \leq J^\pi \leq 3^+$;

— $^{9}Be + {}^{3}He$ channel at energy corresponding to 26.9 MeV of ^{12}C (laboratory ^{3}He energy 0.82 MeV) is open only to spin and parity values $1^- \leq J^\pi \leq 2^-$ and $0^+ \leq J^\pi \leq 3^+$;

— therefore, the level of ^{12}C at 26.9 MeV can be only $J^{\pi} = 0^-, 3^-, 4^-$ since these values are »opened« in $^{11}B + p$ channel and »closed« in $^{9}Be + {}^{3}He$ channel. This reduction of experimentally possible choices did not exclude the mentioned theoretical prediction[4], stating $J^{\pi} = 3^-$.

It is a useful experience to see that in cases when the compound nucleus state parameters cannot be reached by input channel of a reaction, the process is forced to undergo by direct mechanisms (understanding that the assumption of having continuous high density of all compound levels is, in fact, another description of having direct mechanisms). This is the case even at low energy, where the purity of direct mechanism may be governed by J forbidness of compound state formation.

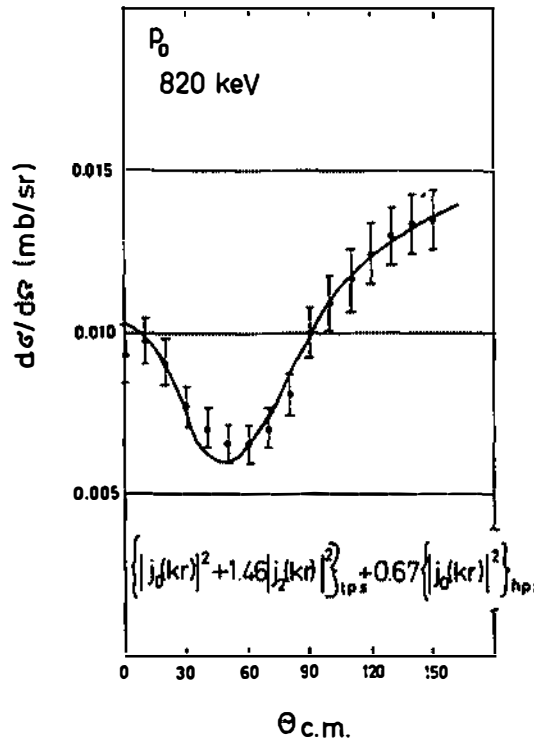

Fig. 9. Angular distribution of p_0 group at 820 keV ^{3}He energy. Solid line is the theoretical curve for uncoherent mixture of two-particle stripping and heavy-particle stripping.

Once we are sure to be dealing with the direct mechanisms, the additional information might be contained in the angular distributions given in Figs, 5, 6 and 7. Before our work, the angular distributions of proton groups from $^{9}Be(^{3}He, p)^{11}B$ reaction were determined and analysed by other authors[5, 7, 8, 9, 10, 11] for ^{3}He energy ranging from 1 MeV to 10.2 MeV. These analyses indicated the important role of two-particle stripping mechanism and we tried to proceed with the compar-

ison of this mechanism with our data at lower energy. The full curves in Figs. 5, 6 and 7 represent the calculation of two-particle stripping in the formulation of Newns[12], where:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \sum_l A_l \, |j_l(Kr)|^2$$

with $K = K_{^3\mathrm{He}} - (M_l/Mf)\, K_p$. The constants A_l were found by fitting the theoretical with experimental curves. Differently from other authors, we did not take the freedom of changing the stripping radius r for each proton group separately, but we kept a single value $r = 6.5$ fm, which seems to us to be a more stringent and a more appropriate assumption. As seen from Figs. 5, 6 and 7, the fit varies from being excelent in some cases to rather poor in the others, but, in average, it gives an idea that two-particle stripping is the predominant mechanism in this reaction. Moreover, it seems that even better fits are obtainable if other direct mechanisms, together with two-particle stripping, are introduced. So, for a typically unsatisfactory fit by two-particle stripping at 820 keV (p_0 group), we tried to add, uncoherently also a contribution of heavy-particle stripping mechanism. As it is seen from Fig. 9, this gave an almost perfect fit. Therefore, it seems to be obvious that our data may be explained by direct mechanisms.

References

1) J. A. Becker, J. D. Fox, Nucl. Phys. **42** (1963) 669;
2) R. G. Allas, S. S. Hanna, L. Mayer-Schutzmeister and R. E. Segel, Nucl. Phys. **58** (1964) 122;
3) L. Feldman, B. B. Baliga and M. Nessin, Phys. Rev. **157** (1967) 921;
4) N. Vinh-Mau and G. Brown, Nucl. Phys. **29** (1962) 89;
5) W. R. Coker, M. M. Duncan, J. L. Duggan and P. D. Miller, Nucl. Phys. A **91** (1967) 97;
6) M. R. Aleksić, R. V. Popić, D. M. Stanojević and B. Z. Stepančić, Fizika, **2** (1960) 113;
7) H. D. Holmgren, M. L. Bullock and W. E. Kunz, Phys. Rev. **104** (1956) 1446;
8) E. Almqvist et al., Bull. Am. Phys. Soc. **1** (1956) 195;
9) E. A. Wolicki, H. D. Holmgren, R. L. Johnston and E. G. Illsley, Phys. Rev. **116** (1959) 1585;
10) S. Hinds and R. Middleton, Proc. Phys. Soc. A**74** (1959) 196;
11) S. Hinds and R. Middleton, Proc. Phys. Soc. A**76** (1960) 754;
12) H. C. Newns, Proc. Phys. Soc. A**76** (1960) 489.

J-ZABRANJENOST MEHANIZMA SLOŽENOG JEZGRA U SLUČAJU $^{9}Be + {}^{3}He$ REAKCIJA NA NISKIM ENERGIJAMA

K. M. SUBOTIĆ, D. M. STANOJEVIĆ, M. R. ALEKSIĆ i B. Z. STEPANČIĆ

Institut za nuklearne nauke »Boris Kidrič«, Beograd

i

R. V. POPIĆ

Prirodno-matematički fakultet Beograd
Institut za nuklearne nauke »Boris Kidrič Beograd

SADRŽAJ

U intervalu energija ^{3}He od 500 keV do 1100 keV istraživane su reakcije $^{9}Be(^{3}He, n)^{11}C$, $^{9}Be(^{3}He, n\gamma)^{11}C$, $^{9}Be(^{3}He, p\,\gamma)^{11}B$ i $^{9}Be(^{3}He, p)^{11}B$ u cilju dobijanja više informacija o nivou 26,9 MeV u složenom jezgru ^{12}C kao i radi proučavanja mehanizma ovih reakcija. Ekscitacione funkcije gama zraka i protonskih grupa nisu pokazale rezonantnu strukturu u ovoj energetskoj oblasti. Odsustvo rezonance, koja bi odgovarala ekscitaciji nivoa od 26,9 MeV u ^{12}C, može se objasniti time da, zbog odredene J vrednosti ovog nivoa i nepostojanja ove J vrednosti u ulaznom kanalu, ne dolazi do formiranja složenog jezgra u reakciji. Izbor vrednosti karakteristika ovog stanja ograničena je zato na $J^{\pi} = 0^{-}$, 3^{-}, 4^{-}. Nadeno je da je zato direktni mehanizam, dvostruki striping i teško-čestični striping, dominantan i na ovako niskim energijama.