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ON THE PROPERTIES OF FEW-NUCLEON SYSTEMS AT THE HIGH EXCITATION LEVEL

1979

Комаров В.И. **E1 - 12749**

О свойствах малонуклонных систем при высоких возбуждениях

Обсуждается поведение малонуклонных систем в таких условиях, когда взаимодействие с высокоэнергичной частицей переводит малонуклонную систему в непрерывное состояние группы свободных нуклонов с инвариантной массой, превышающей исходную на величину порядка 100 МэВ.

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Komarov V.I. **E1 - 12749**

On the Properties of Few-Nucleon Systems at the High Excitation Level

The behaviour of few-nucleon systems is considered in their interaction with an energetic projectile that transits the few-nucleon system into the continuum state of unbound nucleons with the invariant mass exceeding the initial by approximately 100 MeV.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubno 1979

The subject of the paper is the behaviour of few-nucleon systems (FNS) in the conditions of high excitation.

We define the excited FNS $(kN)^*$ as the FNS in the final state of an a projectile scattering on the $[kN]$-system of nucleons

$$a+[kN] \to a'+(kN)^* \tag{1}$$

if the following two conditions are satisfied:

(i) The invariant mass $M_{inv}^{fin.st}$ of the system $(kN)^*$ exceeds the initial mass $M_{inv}^{in.st}$ so that

$$\Delta M_{inv} = M_{inv}^{fin.st} - M_{inv}^{in.st} \gtrsim 100\ MeV\ ; \tag{2}$$

(ii) The momentum p_i of nucleons, emitted in the decay of $(kN)^*$ exceeds the Fermi momentum of nucleon in the target nucleus frame:

$$p_i > p_F \approx 1.4\ fm^{-1}, \quad (i=1,2,\dots k)\ . \tag{3}$$

The invariant mass of FNS in the initial state is assumed to be equal to $M_{inv}^{in.st} = kM_N - B$ if $[kN]$ is the light nucleus with the mass number k and the binding energy B (M_N is the nucleon mass), and $M_{inv}^{in.st} = k M_N$ if $[kN]$ is the FNS contained in the target nucleus with the mass number $A>k$. As we are interested in the continuum states of the FNS, the invariant mass in the final state is equal to $M_{inv}^{fin.st} = \{(\sum_{i=1}^{\ell} \varepsilon_i)^2 - (\sum_{i=1}^{k} \vec{p}_i)^2\}^{1/2}$, where ε_i and $\vec{p}_i$ are the energy and the 3-momentum of the particles emitted in the $(kN)^*$-decay respectively. In the general case ℓ value is not equal to k because the $(kN)^*$ decay can proceed with the production of the lightest nuclear fragments F_m : $(kN)^* \to N_1 + \dots + N_{k-m} + F_m$, or the particle production, for example $(kN)^* \to N_1 + \dots + N_k + \pi$. In a "nucleon" mode of the decay

$$(kN)^* \to N_1 + \dots + N_k \tag{4}$$

ΔM_{inv} with an accuracy of binding energy is equal simply to

$$\Delta M_{inv} \approx \{(\sum_{i=1}^{k} \varepsilon_i)^2 - (\sum_{i=1}^{\ell} \vec{p}_i)^2\}^{1/2} - kM_N\ .$$

In the case of fragments emission the condition (3) should be supplemented by the non-equality condition

$$P_m > P_{mF} \approx \sqrt{\frac{m(A-m)}{A-1}}\, P_F ,$$

where P_m is a fragment F_m momentum in the target nucleus frame.

It is obvious that the conditions (2) and (3) separate such events of scattering (1) that can be realized by particle a interaction with a single nucleon without essential influence of other FNS nucleons only with a small probability. It should be expected that the better is the fulfilment of (2) and (3) non-equalities the smaller is this probability. Really, the condition (3) means that all nucleons of the FNS take part effectively in the scattering process and it is very unlikely that a part of them are the spectators only. The condition (2) provides the possibility of the scattering (1) proceeding in a volume with a linear size less than the average distance $\bar{\ell}_{NN}$ between nucleons in the nuclei. In fact, the linear size ℓ of a system which receives the energy transfer $\Delta\mathcal{E}$ can not be less than $\sim\hbar c/\Delta\mathcal{E}$ and if we want to make possible the proceeding of the process (1) in the volume with ℓ-value less than $\bar{\ell}_{NN}= 1.7$ fm it is necessary to transfer into the system at least the energy $\Delta\mathcal{E} \gtrsim \frac{\hbar c}{\bar{\ell}_{NN}} \approx 120$ MeV. It should be noted that high invariant momentum transfers are not required in the process (1). In particular, the process can take place at distances $\ell < \bar{\ell}_{NN}$ even if a 4-momentum $\sqrt{|t_{aa'}|}$ transferred by the particle a is arbitrarily close to zero. It is essential only that the non-equality

$$\sqrt{|t_{aa'}|}\cdot S \geqslant m_a \left[2\,\Delta M_{inv}\, M_{inv}^{in.st} + (\Delta M_{inv})^2\right]$$

is satisfied. (S is the squared invariant mass of $(a+[kN])$-system, and m_a is the mass of the particle a).

Thus, when the conditions (2) and (3) are satisfied one can expect the appearance in the few-nucleon systems of certain specific properties which are not observed when the interaction proceeds via the quasifree scattering on the single nucleons or on their common nuclear potential when the residual nucleus remains in the ground or low excited state. It is clear that the above mentioned conditions are only necessary but they are not sufficient ones for the appearance of any collective properties in the few-nucleon systems, and only experiments can give an answer to the question -

are any new properties of FNS really observed in such conditions and thus is there any sence in speaking about highly excited states of the few-nucleon systems or not ?

Let us consider now the widest group of experiments which as we suppose have close connection with the problem. We mean here the well known experiments (see, e.g., ref. /1/) of inclusive type, where the backward production of the fast nucleons (or the light fragment) is observed in the reactions

$$a + A \rightarrow N\,(T_N \gtrsim 30\,\text{MeV}\,,\ \theta_N \gtrsim 90^\circ) + \dots \quad . \tag{5}$$

The general property of such a production at high incident energies T_0 of a projectile are the spectra of an exponential form

$$\frac{\mathcal{E}_N}{P_N^2\,\sigma_{tot}^{in}}\,\frac{d^2\sigma}{d\Omega_N\, dP_N} = A_0\, exp\,(-A_1 P_N^2)\,, \tag{6}$$

(σ_{tot}^{in} is a total cross section of the inelastic aA-interaction), where A_0 and A_1 only slightly depend on the type and energy of the projectile and the slope parameter A_1 on the mass number A of the target nucleus. The similar behaviour is also observed in the intermediate energy region with the only difference that A_1 monotonously tends to the asymptotic value $A_1^{as} \simeq$ 10-15 $(\text{GeV/c})^{-2}$ when T_0 value increases.

At first sight this phenomenon has a weak relation with the properties of few-nucleon systems because the main part of these data is obtained with intermediate and heavy target nuclei and there is no direct way to determine a number of nucleons taking part in the interaction effectively. Thus there is nothing surprising in the fact that a great number of very different hypothesis were proposed to explain the observed regularities. Some of these hypothesis contain ideas about the abnormally high intranuclear momenta /2/, high densities of nuclear matter /3/ or the specific mechanisms peculiar only to high incident energies (e.g. the quark-parton mechanisms /4/, the fireball production /5/ and so on). Nevertheless, the most natural picture is, from our point of view, the next one. The energetic spectra of nucleons emitted backwards are clearly distributed at two specific regions:

A) A so-called low-energetic "evaporation"-region, that is characterised by the nuclear temperature $T \simeq 10$ MeV and is caused by the decay of an intermediate nucleus, i.e. the decay of excited state of the nucleus as a whole at the excitation level of an order of 10 MeV. A weak angular anisotropy of the nucleon production in this spectrum part observed in the laboratory frame is caused by the motion of the intermediate nucleus that accepts a certain 3-momentum transfer from a projectile.

B) A high-energy region of spectra, that is described by "the temperature" $T \approx 50$ MeV and is a result of the decay of a few-nucleon part of the target nucleus. The excitation level of this nucleus part is higher than about 100 MeV. The sizeable angular anisotropy of the nucleon production in this region of spectra means only that such excited group acquires in the excitation process a velocity, considerably larger than the velocity reached by the whole nucleus in the first case.

With the aim of testing this picture of the backward emission of the fast nucleons let us calculate the spectra of protons from the hadron-nucleus interactions /6/ in the next assumptions:

1) A hadron h interacts with the FNS in the target nucleus accordingly to the process (1). It scatters predominantly at small forward angles increasing the invariant mass of the nucleon group. The protons are emitted backwards in the decay (4). We assume the decay (4) to proceed by the statistical way.

2) The relative probability of increasing $M_{inv}^{in.st}$ at the definite quantity ΔM_{inv} does not depend on the type and energy of the projectile h. The distribution of the excitation probability over ΔM_{inv} values ("the FNS excitation spectrum") is the intrinsic property of the FNS effectively taking part in the process (1) and depends only slighly on the number k of the nucleons in the group, the mass number of the target nucleus A and on the spin-isospin state of the FNS when the values ΔM_{inv} exceed about 100 MeV. The excitation spectrum was presumed for the specific calculations to have the form

$$W_k(\Delta M_{inv}) = exp(-\Delta M_{inv}/M_{exc})/(1-exp(-\mathcal{E}_k^{max}/M_{exc})), \quad (7)$$

where M_{exc} is the characteristic parameter of the excitation probability and $\mathcal{E}_k^{max}$ is the maximal excitation energy, kinematicaly accessible in the process (1). If the FNS excitation that is of interest for us here proceeds via the excitation of the nucleons composing the FNS (i.e., in the first line, via the Δ (1232) resonance or the pion production) then it is natural to take the pion mass for the parameter M_{exc} value.

3) The process (1) has a quasidiffractional character, i.e., the scattering of the hadron h approaches the diffractional one

with increasing energy T_0. So the probability of scattering at an angle θ^* in the $(h+[kN])$-system centre of mass frame with a momentum p_k^* can be assumed in the form, describing the main peak of the diffractional scattering on the black sphere:

$$W_k(\theta^*) = exp(-(\theta^* p_k^* k^{1/3} R_{c2})^2), \quad (8)$$

where R_{c2} is the free parameter of the model.

4) The total cross section of the interaction (1) at the nucleon groups of the nucleus can be determined with an accuracy up to a constant factor $\mathcal{P}$ by the geometrical cross section of FNS $[kN]$ and the combinatorial probability to find it in the nucleus:

$$\sigma_{k(hA)} = \mathcal{P}\pi(k^{1/3}R_{c2} + \sqrt{\sigma_{hN}/\pi})^2 \frac{A}{k!}(R_k/R_0)^{3(k-1)} \cdot exp(-(R_k/R_0)^3), \quad (9)$$

where σ_{hN} is the total cross section of hN interaction, the parameter R_0 deremines the nucleus radius $R_A = A^{1/3}R_0$ and R_c determines the cluster radius $R_k = k^{1/3}R_c$. Supposing the average density of nucleons in the FNS to be close to the average nuclear density we take $R_c = R_0$. A Gaussian with the standard deviation $\sigma_p(k) = \sqrt{k/2}\, 90$ MeV/c is used as a momentum distribution of the FNS in the nucleus. Secondary interactions of the hadrons or outgoing protons in the nucleus are not taken into account.

The proton spectrum is calculated under these assumptions as a noncoherent summ of the partial spectra produced on the FNS with different k values:

$$d^3\sigma/d\vec{p}_p = \sum_{k=2}^{k_{max}} d^3\sigma_k/d\vec{p}_p, \quad (10)$$

where

$$d^3\sigma_k/d\vec{p}_p = (\sigma_{k(hA)}/R_k^{FM})(d^3R_k^{FM}/d\vec{p}_p). \quad (11)$$

Here R_k^{FM} and $d^3R_k^{FM}/d\vec{p}_p$ are, accordingly, the integral of the phase space and its derivative over $\vec{p}_p$. The integration over the phase space was performed by the Monte-Carlo method, introducing two weight functions in the form (7) and (8) which have the meaning of the squared matrix element $|A_{ji}|^2$.

Let us close now the values of the parameters R_{c2} and $\mathcal{P}$ by comparing the calculated spectra with the experimental one for the reaction $p + {}^{12}C \to p + X$ /7/ at 640 MeV and proton emission angle θ_p = 122°. Fig. 1 shows the result of this comparison with R_{c2} = 0.25 fm and $\mathcal{P}$ = 0.14. With this values we can calculate the angular dependence of the slope parameter A_1 which turns out to be close to the experimental dependence (see Fig. 2a) and to reproduce the scaling behaviour of the energy dependence of this parameter (see Fig.2b).

We see that the most essential characteristics of the inclusive data can be explained using the most simplified assumptions about the nuclear properties and the reaction mechanism. The values of the parameters R_{c2} and σ_ρ obtained in this way indicate the angular distribution of the hadron-FNS-scattering to be close under studied conditions to that in the diffraction scattering on the black sphere

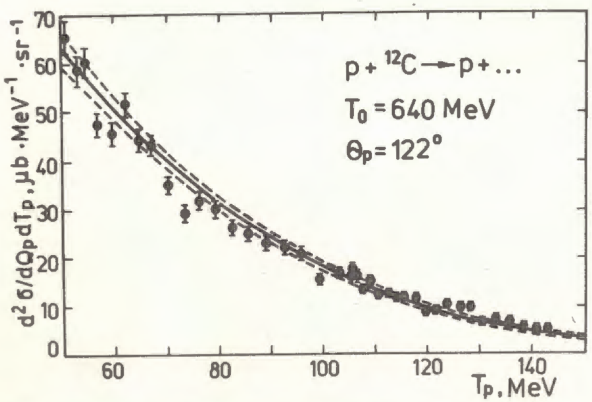

Fig.1 The energetic spectra of protons. The curve with the error corridor - the calculation, the points - the experiment /7/.

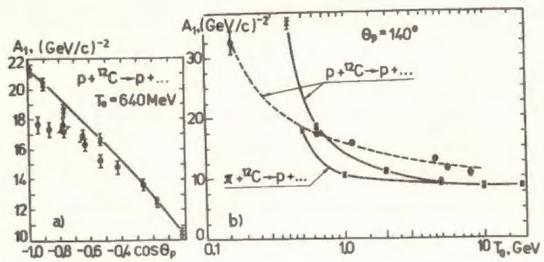

Fig.2 Angular (a) and energetic (b) dependence of the slope parameter A_1 for the inclusive proton spectra. ✕- the calculation; ● - the experiment (see refs. in /7/).

of the radius $r_k = 1.81\, k^{1/3} R_{c2}$ ($r_2 = 0.57$ fm) and the total cross section σ_k of the interaction (1) with high excitation of $[kN]$ is equal to

$$\sigma_k = 0.14\pi \left(k^{1/3} R_{c2} + \sqrt{\sigma_{hN}/\pi}\right)^2 \frac{1}{k!} \left(R_k/R_0\right)^{3k} \cdot \exp\left(-\left(R_k/R_0\right)^3\right), \qquad (12)$$

So we obtain σ_2 = 6.8 mb and σ_3 = 6.6 mb. These large cross section values can be understood if one keeps in mind the absence of the suppression caused by the high momentum transfers. In the crude approximation the total cross section σ_k^{hexc} of the scattering (1) with high excitation of the FNS $[kN]$ can be written in the form

$$\sigma_k^{hexc} \simeq k^n \cdot \sigma_{aN}^{in} \cdot W_k \ , \quad n = 1 \div 2 \ , \qquad (13)$$

where σ_{aN}^{in} is the total inelastic cross section of the aN-interaction, n is determined by the degree of coherence of the nucleon excitation and W_k is the probability to dissipate the excitation energy of single nucleon over the system of nucleons. Comparing (12) and (13) we find $W_2 \approx 0.14 \div 0.27$ and $W_3 \approx 0.06 \div 0.17$.

It should be noted that the calculation results only weakly depend on the details of the exact form of the weight functions (7) and (8) because the observed spectrum is a composition of the partial spectra with several values of k. The statistical character of the inclusive spectra is a consequence of existence of numerous possibilities for the proton production with a certain $\vec{p}_p$ value; various values of k $(2 < k \leq k_{max} = 6 \div 8)$, decay (4), Fermi motion of the $[kN]$-group centre of mass. The observed spectra are influenced also by the factors not taken into account in the calculation /6/: multiple hadron interactions in the nucleus, internal Fermi motion in the FNS, partial transfer of the FNS energy to the residual nucleus and final-state interactions of protons emerging from the nucleus. However, it is essential from our point of view that besides these rather obvious factors causing the statistical behaviour of the inclusive backward production of fast nucleons, the quated model takes into account the more profound reason of the statistical nature of the phenomenon. This reason is connected with the few-nucleon system properties. First of all, we suppose that the energy carried into the FNS is distributed among the nucleons in such a way that they acquire the available phase space in a random occupation. Secondly, we introduce for describing of the FNS such a characteristic as continues excitation spectrum, that does not depend of the properties of a projectile. At first sight, such an approach seems to be not expedient for describing a system consisting of a small number of particles. Really, one or two Feynmen diagramms are considered,[8-10] as a rule, for the mechanism of backward production of fast nucleons in the interactions with the lightest nuclei (deuteron, helium). Nevertheless, one should remember that these undoubtedly usefull calculations have in general, as it is evaluated by the experts,"the shooting in" character (see e.g. ref. [9]). Taking into account the short-range correlations in the relativistic composite system the exact description of bound nucleons should consider the set of states, not only nucleon ones but also the states including pions and barion resonances. So, one should take into account,e.g.,for the deuteron case not only NN-states, but $\Delta\Delta$-, $NN\pi$-, $NN\pi\pi$, NN^*-states and so on. The correct calculation including effects of short-range correlations in the initial and final states and the possibility of nucleon excitations, evidently, turns this problem to be too complicated for the detailed analysis of a microscopic type (for example, by the consideration of several Feynman diagramms). It is possible that the processes of high momentum or energy transfer to FNS cannot be in principle described when one restricts himself by a small number of ways for such a transfer, and the only adequate description is a statistical one. In this aspect the FNS excitation at level $\mathcal{E}_{exc} \gtrsim m_\pi$ may occur to be analogous to the excitation of intermadiate or heavy nuclei at the energies of about 10 MeV.

If this situation really takes place one should consider the experimentally observed nondependence of the slope parameter of the inclusive spectra on the type and energy of a projectile ("nuclear scaling"[11]) as the indication to the nondependence of the FNS excitation spectra on the properties of incident particles. An observed weakness of mass-number dependence of the slope parameter is a direct consequence of a small difference between the wave functions of few-nucleon groups in various target nuclei at relative internucleon distances $\ell < \ell_{NN}$. This means that the excitation spectra of the FNS should only weakly depend on the type of a target nucleus. In this sense the FNS excitation spectra have a universal character. It is clear that the assumption about the identity of excitation spectra for different FNS,(different spin-isospin states and so on) made in the concrete calculation [6] is very crude and does not contradict in qualitative manner only to inclusive data.

We have dealt so far with the one-particle differential cross-sections for the type (10) process on light and intermediate nuclei

and have been convinced of impossibility to obtain detailed information about such properties of FNS as their excitation spectrum. It is not surprising because the inclusive measurements satisfy incompletely the requirements (1)-(3): only one (observed) particle has a momentum $p \gtrsim p_F$ (the condition (2)) and is emitted in the kinematical region forbidden for the interaction with the nucleon in rest, but allowed for the process (1) with $k > 1$.

Let us consider now the experiments where the requirements (1)-(3) are fulfilled in a more complete way. The simplest step in this direction may be the measurement of the two-particle differential cross sections. As an example we examine the experiment [12] where the reaction

$$p_0 + {}^{12}C \rightarrow p_1 + p_3 + \dots \qquad (14)$$

at 640 MeV was studied. The spectra of protons p_3 emerging backwards ($|\theta_3|$ = 105°-155°) with the energy from 50 up to 145 MeV in coincidence with protons p_1 of an energy T1 (255 MeV < T1 < 330 MeV) emitted forwards ($|\theta_1|$ = 10°-40°) coplanar with p_0 and p_3 - momenta were detected. Such a choise of the kinematic conditions accords with the process

$$p_0 + [pN] \rightarrow p_1 + N + p_3 \qquad (15)$$

as scattering (1) and ΔM_{inv} for $\theta_1 = -12°$, $\theta_3 = 122°$ is equal to about 250 MeV. In fig. 3 the dependence of the measured cross section (without the cascade contamination, see [13]) on four kinematic variables is shown. The calculation, similar to one considered above for the inclusive process, is normalized at the experiment and is shown in the same figure (the curve 3). Opposite to inclusive cross sections only scattering (15) on two-nucleon systems was left here. It is seen that the calculation describes the experimental dependences quite satisfactorily if one takes almost the same as for the inclusive data (M_{exc} = 150 MeV and R_{c2} = 0.3 fm) values of parameters M_{exc} and R_{c2}.

Just these two-particle data were considered also in the paper of J.Knoll [14], where independently of us the statistical picture of projectile interaction with few-nucleon groups in nuclei has been developed. The main difference of conception [14] with our calculations lies in the assumption that all available energy is distributed in a statistical way among the particles taking part in the interaction. Such a conception succeeds to describe the inclusive data at the certain incident energy in the intermediate region. However, it is clear that pure statistical consideration must fail in reproducing

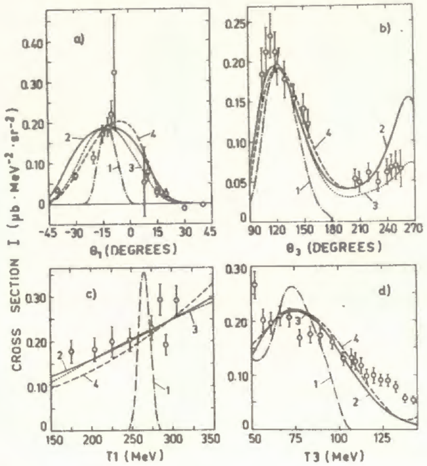

Fig.3 Two-proton differential cross sections of the reaction (14) at 640 MeV. The points - experiment /12/; the curves - calculation (in arb.units) for the process (15): 1 - relative momentum in [pN]-pair is equal to zero; 2 - phase space distribution; 3 - $|A_{ji}|^2 \sim exp(-\Delta M^{(12)}_{inv}/M_{exc})$, M_{exc} = 0.15 GeV; 4 - $|A_{ji}|^2 \sim exp(-\theta^* p^* \cdot \sqrt[3]{2}\, R_{c2}))$, R_{c2} = 0.25 fm.

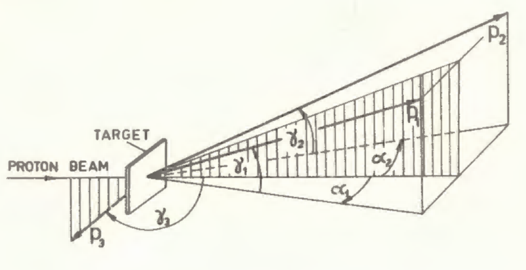

Fig.4 Geometric conditions for the quasifree knockout of proton pairs in the experiment /15/.

the scaling behaviour of the cross sections with increasing T_0. The fact of the forward emitted leading particle production that carries off the main part of available energy cannot be reproduced also. The last effect evidently turns up already at intermediate energies where the observed asymmetry of the angular distributions /12/ (see fig. 4a and b) is not reproduced by the calculation /14/.

Still more definite information about the properties of the high excited FNS can be obtained in the exclusive measurements where all fast particles produced in the process (1) are detected. Such an approach is necessary in the study of a certain few-nucleon system contained in the heavier target nuclei. As an example we consider here the experiment /15/ where the reaction

$$P_0 + {}^{12}C \to P_1 + P_2 + P_3 + \cdots \qquad (16)$$

was investigated at the 640 MeV incident energy. The kinematic conditions were chosen in accordance with the quasi-free backward scattering in the process

$$P_0 + [2p] \to P_1 + P_2 + P_3 \, . \qquad (17)$$

Three fast protons were detected in coincidence (see Fig. 4) in symmetric ($\alpha_1 = \alpha_2 \equiv \alpha; \alpha_3 = 0$) and noncoplanar ($\gamma_1 = \gamma_2$ = 12°; γ_3 = 122°) geometry. Each of two protons P_1 and P_2 emerging forwards was detected in the energetic range of 235-310 MeV. The spectra of protons P_3 emitted backwards were measured in the range of 30-105 MeV. In this experiment all three requirements (1)-(3) are satisfied and the value ΔM_{inv} is near 270 MeV at all angles α studied. The isospin state of the FNS being an effective target is determined unambigously in this case and isospin is equal to T = 1.

Energetic and angular distributions obtained at the backward proton energy higher than 50 MeV are qualitatively described by the same model of excited FNS and with the same values of the parameters M_{exc} and R_{c2} as for the two-proton cross sections considered above (see figs. 5 and 6).

The comparison of the absolute values of two-proton and three-proton cross sections shows that the fraction of squared matrix elements for three-proton ($F^{(3)}$) and two-proton ($F^{(2)}$) cross sections is equal to $F^{(3)}/F^{(2)} \approx (1 \div 3)\, 10^{-2}$. As opposed to the process (17) the effective target in the process (15) may be [pp]- and [pn]-groups. So this fraction means that excitation of [pp]-groups is significantly suppressed with reference to [np]-groups excitation.

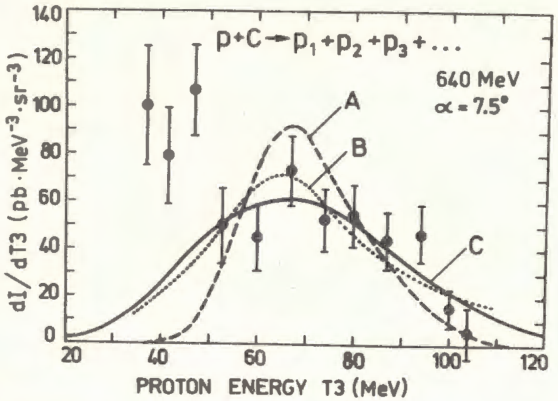

Fig.5 Energetic spectra of protons emitted backwards in the $^{12}C(p,3p)$ reaction at 640 MeV /15/. The curves - calculation (in arb. units) for the process (17): A - without Fermi motion of [pp]-pair; B - Fermi motion of pair is taken into account; C - Fermi motion and $|A_{ji}|^2$ in accordance with (8) at R_{c2}= 0.25 fm.

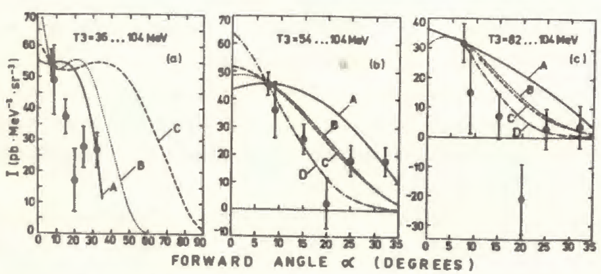

Fig.6 Angular dependence of the three-proton differential cross section in the reaction $^{12}C(p,3p)$ at 640 MeV for three intervals of energy T3 of backward emitted protons /15/. (a) - the curves are the phase space distributions (in arb.units) for the reactions: A - (17) with Fermi motion of [pp]-pair; B - $p_0+[ppN] \to p_1+p_2+p_3+N$; C - $p+{}^{12}C \to p_1+p_2+p_3+{}^{10}Be$; (b) and (c) - the curves are calculations (in arb.units) for the process (17) with Fermi-motion; A - $|A_{ji}|^2$= const; B - $|A_{ji}|^2 \sim exp(-\Delta M^{(12)}_{inv}/M_{exc})$ and M_{exc} = 0.15 GeV; C - $|A_{ji}|^2$ in accordance with (8) and R_{c2} = 0.25 fm; D - the same as "C", but R_{c2}= 0.4 fm.

The example considered above shows that in exclusive and semi-exclusive experiments one can separate the definite channel of the FNS excitation and the excitation spectra of FNS for such channels as well as the angular distributions of the leading particles can be studied. If the scattering of a projectile in the process (1) has a quasi-diffractional coherent character then the angular distribution of a' in (1) should have the width $\Delta\theta_k \approx (p_k^* k^{1/3} R_{c2})^{-1}$. The assumption that the excitation spectrum $W(\Delta M_{inv})$ can be described by the same function for different targets and projectiles can be checked experimentally also: the distributions over ΔM_{inv} can be measured directly at least for the light nuclei in the wide range of nuclear reactions. Thus, one of the most interesting question of the $(p,3p)$-reaction study is the measuring of the $W_{2p}(\Delta M_{inv})$. As a consequence of the excitation spectra universality one should expect definite relations between the characteristics of very different nuclear reactions where the conditions (1)-(3) are satisfied. For example, the slope parameters for spectra of the fast fragments (^2H, ^3H, ^3He) emitted backwards in hadron-nucleus reactions, can be calculated if the slope parameters for the backward proton spectra are known. Such a correlation follows evidently from the existence of different modes of $(kN)^*$-decay. One can obtain also the relation between the spectra of fast pions produced in the reaction $d+A \to \pi(0°)+\dots$ and energetic protons emitted in $h+d \to h'+N+p(180°)$.

Let us consider at last the experimental data about the fast particle interactions with the lightest nuclei. The experiments performed in the Laboratory of High Energies of JINR (see ref. /16/) had shown that inclusive spectra of fast protons produced backwards in interaction with such nucleus as ^4He still qualitatively conserve the same behaviour that they have for the heavier target nuclei. The sizeable difference from the single exponent of the type (6) turns up only in the proton spectra from the interaction with the simplest nuclear system deuteron at 0.97 GeV incident proton energy /17/. Let us test the consistency of the considered above conception with the most "pure" case of interaction in the few-nucleon systems. In fig. 7 the energetic spectra of protons emitted in the reaction

$$p+d \to p+p+n \qquad (18)$$

in the three angular intervals of the backward hemisphere at T_0 = 0.97 GeV are shown. The curves show the result of calculation similar to one, described above (see ref. /6/ also) with M_{exc}= 0.14 GeV and R_{c2}= 0.25 fm. It is seen in fig. 7 that qualitative behaviour

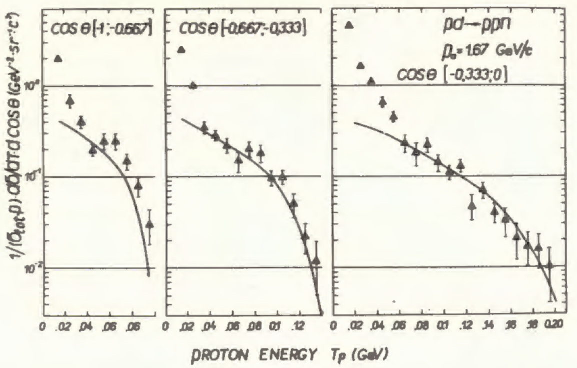

Fig.7 Inclusive spectra of protons from the reaction (18) at 0.97 GeV for three angular intervals of proton emission /17/. The curves - calculation in the model of FNS excitation.

of the experimental data can be reproduced in the frame of the excited FNS model. The absolute cross section value coinsides with the experimental one if the value σ_2 equal to 5.0 mb is taken for normalyzing. Comparing with the value $\sigma_2^{hexc} \approx 2^n \cdot \sigma_{pN}^{in} \cdot W_d$ we find W_d = 0.05÷0.1. Therefore, the probability of excitation is still rather high even for such a friable system as the deuteron.

The excited FNS model can evidently predict angular and energetic distributions for the reaction (18) in the wide range of incident energies T_0 from 0.5 GeV up to energies where the value of σ_{pN}^{in} is still known. The differential cross section for the process $a+d \to p(\theta_p \gtrsim 90°)+...$ can be predicted also for the arbitrary projectile a for which the σ_{aN}^{in} value is known. It is obvious that the model says nothing about the exact mechanism of excitation and cannot replace in any degree the calculations of the type described in ref. /18,19/.

In conclusion, we summarize the above consideration:

1) There exist at present the experimental data that can be interpreted as a manifestation of the high ($\Delta M_{inv} \gtrsim$ 100 MeV) excitations in few-nucleon systems.

2) Few-nucleon systems show certain specific properties in kinematic conditions of high energy excitations: their behaviour can be

described by the introduction of the continuum excitation spectra only weakly depending on the type of target-nucleus and properties of projectile. The mean value of the excitation spectra is close to 0.15 GeV.

3) The FNS excitation by energetic particles occurs predominantly in quasidiffracional scattering of projectiles. The angular distributions of leading particles are determined by the linear size of FNS about (0.5-1.0) $k^{1/3}$ fm.

4) The probability of high excitation of FNS by an arbitrary incident particle a has a sizeable value and determines the total cross section of about $k\,\sigma_{aN}^{in} \cdot W_k$, where $W_k \approx$ 0.05-0.3 for k = 2 and 3.

We must stress once more that these conclusions are based still on the limited experimental data and so have rather heuristic meaning.

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