ON THE MECHANISMS OF DEUTERON FORMATION IN ^{16}Op-INTERACTIONS AT A MOMENTUM OF 3.25 GeV/c PER NUCLEON

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An irregularity in the deuteron distribution over the kinetic energy within the range $T_d = 60 \div 90$ MeV in the rest frame of an oxygen nucleus has been observed for the first time for ^{16}Op-interactions at a momentum of 3.25 GeV/c per nucleon. The emergence of this irregularity has been shown to originate from the process of α-cluster decay owing to its absorption of a slow pion.

The study of the mechanisms of fragmentation of relativistic nuclei interacting with nucleons and nuclei is one of the key problems of high-energy physics. In our opinion, one of the most effective methods for the solution of this problem is to study the processes, where light fragments – such as ^{1}H, ^{2}H, ^{3}H, and ^{4}He – are produced [1]. First, it is a result of the fact that the cross-section of the light fragment formation is comparable with the total inelastic cross-section of the reaction, and, hence, the formation of light fragments is a characteristic feature of the nucleus fragmentation process. Second, it was found definitely that a substantial fraction of light fragments is emitted at the earliest stage of the interaction between two nuclei, and, hence, those fragments are carriers of the direct information concerning the interaction dynamics.

This work continues the cycle of researches [1–6] dealing with the fragmentation processes of ^{16}O nuclei with a momentum of 3.25 GeV/c per nucleon occurring at their interactions with protons, being devoted to studying the mechanisms of deuteron formation. We would like to point out that, in our previous works, the essential role of α-cluster structures of an oxygen nucleus in the formation of final fragments has been demonstrated. The methodical issues concerning the obtaining of experimental data with the help of a 1-m hydrogen bubble chamber in a magnetic field, irradiated with a beam of ^{16}O nuclei (the Laboratory of High Energies, JINR, Dubna, Russia), were reported in works [7, 8]. The applied technique allowed the charge of every fragment to be identified, the momentum of the fragment to be measured with a high accuracy, and the fragments of a projectile ^{16}O-nucleus with charges $z \leq 4$ to be distinguished unambiguously by their masses. The statistics of this work comprises 8712 completely measured ^{16}Op-events.

For the physical interpretation of experimental data to be more complete, they were compared with the predictions obtained in the framework of the cascade-fragmentation evaporation model (CFEM), developed for proton-nuclear interactions at intermediate energies [9]. In the framework of CFEM, the process of interaction consists of a few stages: the initial stage of the intranuclear cascade and the final stage which includes the deexcitation of hot excited nuclei and the formation of final fragments. For light nuclei such as ^{16}O, the process of Fermi-decay was used as a dominant mechanism of fragment formation. Moreover, this model considers the contributions to final states made by decays of the unstable nuclei ^{5}He, ^{5}Li, ^{8}Be, and ^{9}B. It should be noted, however, that the CFEM does not take the mechanism of "evaporation"into account, while considering the formation of light fragments.

Note that the formation of ^{2}H nuclei can take place at all possible stages of the interaction between oxygen nuclei and protons [1, 5, 10]. Deuterons can be formed as a result of such phenomena as Fermi-decay and "evaporation", fusion of relatively fast cascade nucleons [5, 10], decays of excited fragments or the residual nucleus, as well as owing to their direct knocking out from an oxygen nucleus by protons. In work [1], on the basis of the analysis of the deuteron distribution over the total momentum made in the rest frame of the oxygen nucleus, it was demonstrated that the CFEM overestimates the formation of deuterons in the momentum interval 0.1 GeV/$c < p < 0.35$ GeV/c and

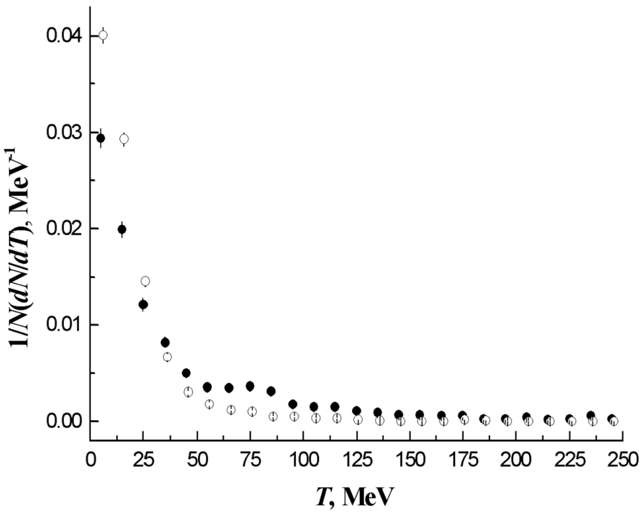

Fig. 1. Distributions of all deuterons over their kinetic energy in the rest frame of an oxygen nucleus: experiment (●) and the CFEM theory (○)

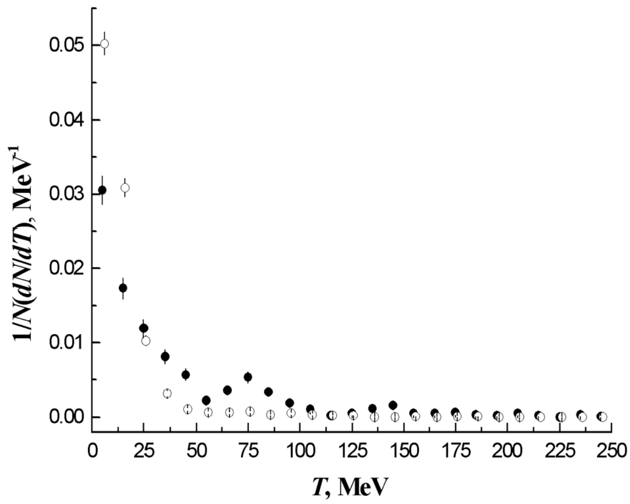

Fig. 2. Distribution of deuterons in events with the total charge of multicharge fragments $\sum z_f = 5 \div 6$ over the kinetic energy in the rest frame of an oxygen nucleus: experiment (●) and the CFEM theory (○)

underestimates the experimental yield of deuterons in the interval $p > 0.4$ GeV$/c$. Earlier [10], we showed that the underestimation of the formation of relatively fast deuterons by the model is connected with the neglecting of the additional mechanism of deuteron formation – the fusion of fast cascade nucleons.

It is natural to expect that the fraction of events with the formation of deuterons should increase with the growth of the destruction degree of the initial oxygen nucleus. For instance, in topologies, where a total charge of multicharge ($z \geq 2$) fragments in the event is equal to $\sum z_f = 6$ (i.e. in topological channels (6), (42), (33), (222), and so on; here, the numbers in parentheses indicate the charge composition of multicharge fragments in the event), the deuteron is formed, on the average, in approximately 20% of the events; while in topology (1), i.e. when there are no the multicharge fragments in the event, one or more deuterons are formed in about 70% of the events.

In Fig. 1, the distributions of all deuterons over their kinetic energy in the rest frame of an oxygen nucleus, obtained in experiment and the CFEM, are depicted. The experimental spectrum has a maximum near $T =$ 0 MeV. The growth of the kinetic energy of deuterons is accompanied, at first, by a drastic decrease of the spectrum up to 45–50 MeV. Further, as is seen from Fig. 1, the experimental distribution of deuterons has a "shoulder" in the interval 60–90 MeV which is absent in the deuteron spectrum calculated theoretically in the framework of the CFEM. A more detailed analysis of the features of the experimental spectrum in topological channels demonstrates that, in topologies with the total charge of multicharge fragments in the event $\sum z_f = 5 \div 6$ – i.e. in topological channels (6), (222), (5), (32), and so on, – a resonance-like peak in the interval 70–80 MeV is observed. This fact is particularly well illustrated in Fig. 2, where the experimental and theoretical (according to the CFEM calculations) distributions of deuterons over the kinetic energy are exhibited for events with $\sum z_f = 5 \div 6$. It is evident from this figure that the theoretical distribution of deuterons, contrary to the experimental one, does not reveal any anomaly in the interval 60–90 MeV, and a resonance-like structure is not observed.

The results of studies of the probable kinematic correlations occurring at the formation of deuterons, multicharge fragments, and protons in topologies with $\sum z_f = 5 \div 6$ in the event can be listed as follows:

(i) the distribution of multicharge fragments and deuterons over the difference between their azimuthal angles is isotropic for every possible value of the kinetic energy of deuterons T_d;

(ii) the distribution of deuterons and protons over the difference between their azimuthal angles is isotropic, if $T_d < 50$ MeV; however, in the range $T_d = 60 \div$ 90 MeV, a tendency for a deuteron and a proton to be emitted in opposite directions in the azimuthal plane is observed;

(iii) the average kinetic energy of protons $\langle T_p \rangle$ in the interval 0–400 MeV, measured in the rest frame of an oxygen nucleus, is equal to (83.2 ± 1.0) MeV for events without the deuteron yield; while, in events with the formation of a deuteron, it is substantially higher: $\langle T_p \rangle = (102.0 \pm 3.6)$ MeV; in the latter case, the increase of T_d is also accompanied, on the average, by the growth of the kinetic energy of accompanying protons.

The presence of kinematic correlations in the associated yield of protons and deuterons points at an opportunity of their formation as a result of the decay of a strongly excited three- or four-nucleon cluster. Since the resonance-like irregularity in the deuteron spectrum can be clearly distinguished in topologies with the total charge of multicharge fragments in the event $\sum z_f = 5 \div 6$, when only one or two α-clusters of the initial nucleus becomes destroyed, which means that the cascade process is strongly restricted, the kinematic characteristics of deuterons and protons formed in the primary collision event are better preserved in those topologies. One may assume that, if an α-cluster absorbs a slow pion and decays with the formation of deuterons and nucleons, the spectrum of deuterons would be more hard than that obtained in the case of the formation following the mechanisms of "evaporation" or Fermi-decay. The facts that the resonance-like peak in the deuteron spectrum is observed at the energy of about 70–80 MeV, which is close to the half of pion's mass, and that the kinetic energy of associated protons also becomes higher are in good agreement with this assumption. Note that, in work [11], while analyzing the reaction ^{4}Hep →dppn, provided that the momentum of initial ^{4}He nuclei is 8.6 GeV$/c$, the data, which evidenced for the essential role of the mechanism of absorption of a slow pion by the α-cluster in the formation of deuterons, were obtained.

Thus, a conclusion can be drawn that the formation of the irregularity in the interval $T_d = 60 \div 90$ MeV in the distribution of deuterons over their kinetic energy in the rest frame of an oxygen nucleus is associated with the additional mechanism of deuteron formation, namely, the decay of an α-cluster when it absorbs a slow pion.

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ДО ПИТАННЯ ПРО МЕХАНІЗМ УТВОРЕННЯ ДЕЙТРОНІВ В ^{16}Op-ВЗАЄМОДІЯХ ПРИ ІМПУЛЬСІ 3,25 ГеВ/c НА НУКЛОН

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Р е з ю м е

Вперше в ^{16}Op-взаємодіях при імпульсі 3,25A ГеВ/c у розподілі дейтронів за кінетичними енергіями в системі спокою ядра кисню в області $T_d = 60 \div 90$ МеВ виявлено нерегулярність. Показано, що утворення цієї нерегулярності пов'язано з процесом розпаду α-кластера внаслідок поглинання ним повільного піона.