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PROTON SPECTRA FROM 6.3 GEV/C DEUTERON BREAK-UP ON H, D, C, Al, AND Bi NUCLEI

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Спектры протонов от развала дейтронов с импульсом 6,3 ГэВ/с на ядрах H , D, C, Al и Bi

В интервале импульсов от 2,6 до 3,6 ГэВ/с под углом 103 мрад в лабораторной системе измерены спектры протонов, испущенных в результате развала дейтронов с импульсом 6,3 ГэВ/с на ядрах H , D, C , Al и Bi . Измерения проводились на синхрофазотроне ОИЯИ с помощью магнитного спектрометра с проволочными искровыми камерами на линии с ЭВМ. Полученные результаты, в основном, удовлетворительно воспроизводятся в рамках модели многократного дифракционного рассеяния с учетом релятивистской деформации волновой функции дейтрона.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

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Proton Spectra from 6.3 GeV/c Deuteron Break-Up on H , D , C , Al, and Bi Nuclei

The proton spectra resulting from 6.3 GeV/c deuteron break-up on H , D , C , Al, and Bi nuclei were measured at an angle of 103 mrad (lab system) in the momentum interval from 2.6 to 3.6 GeV/c. The measurements were made at the JINR synchrophasotron with one-arm magnetic spectrometer on-line with a computer. The results, on the whole, are reasonably reproduced in the framework of the Glauber multiple scattering model taking into account the relativistic deformation of the deuteron wave function.

The investigation has been performed at the Laboratory of Computing Technique and Automation, JINR.

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Until recently the experimental investigations of the deuteron break-up occurring when relativistic deuterons collide with nuclei consisted mainly in the measurements of proton and neutron yields at angles near to 0° /1-3/ . The analysis of the results of those investigations allowed the main processes resulting in the deuteron break-up to be distinguished. These are the stripping, the coherent diffractive dissociation caused either by nuclear or by Coulomb forces, and the incoherent dissociation of deuterons /4/ .

Another approach to the investigation of the relativistic deuteron break-up consists in the measurements at fixed angles of momentum spectra of protons emitted in the process

$$d + A \to p + X. \qquad (1)$$

This method was used to study the deuteron break-up on protons at an incident deuteron momentum of 2.95 GeV/c /5/ and on nuclei for 3.5 and 5.8 GeV/c incident deuterons /6/ . These investigations gave indications to a certain excess of large-momentum protons. A similar conclusion was made as a result of the studying of the dp → ppn reaction at 3.3 GeV/c using a liquid-hydrogen bubble chamber [7].

During the course of a series of measurements of high-energy deuteron interactions [8] we have performed a measurement of momentum spectra of the protons emitted in the reaction (1) at an angle of 103 mrad (lab system) in the interactions of 6.3 GeV/c deuterons with H, D, C, Al, and Bi nuclei in the interval from 2.6 to 3.6 GeV/c. Under these conditions the explored region of spectator proton momenta ranged, in the frame with the deuteron at rest, from 328 to 370 MeV/c. Therefore, one might expect that protons experienced an interaction with target nucleus in the deuteron break-up process rather than spectator protons from the stripping and the coherent diffractive dissociation of deuterons should contribute to the momentum spectra.

The schematic view of the experimental layout is shown in fig.1. The extracted 6.3 GeV/c deuteron beam of the JINR synchrophasotron was incident on targets of CH_2, CD_2, C, Al and Bi, from 0.8 to 2 g/cm^2 thickness. The flux in the beam ranged from 5.10^8 to 5.10^9 deuterons per pulse with a typical pulse length of 300 msec. The repetition rate was one pulse every 10 sec. The absolute beam monitoring was made by measuring the characteristic activity of ^{24}Na produced in thin aluminium foils placed in the beam just upstream of the targets during calibration runs. Assuming that the cross section for the reaction $^{27}Al(d, 3p\,2n)^{24}Na$ has a weak dependence on the incident deuteron

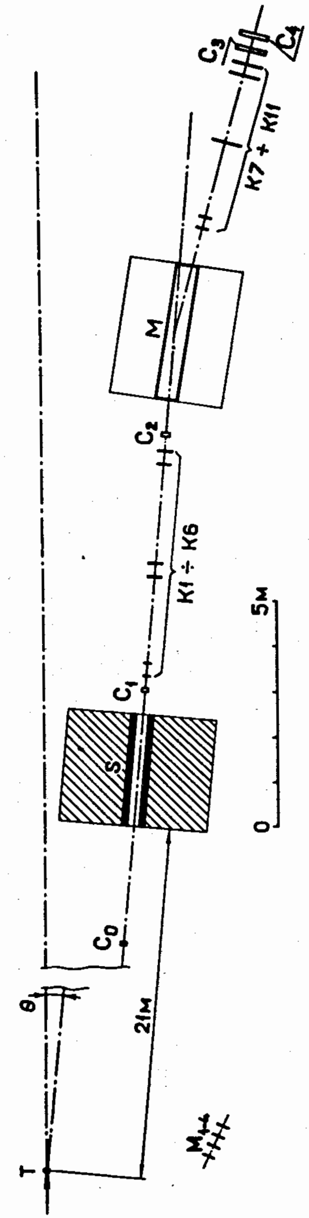


Fig.1. Experimental arrangement. T - target, S - shield, M - analyzing magnet, C_0,..., C_4 - scintillation counters, K1,...,K11 - double - coordinate wire spark chambers, M_{1-4} - monitor.

momentum in the interval from 3.8 to 6.3 GeV/c its value was taken to be (15.25 ± ±1.5) mb [9].

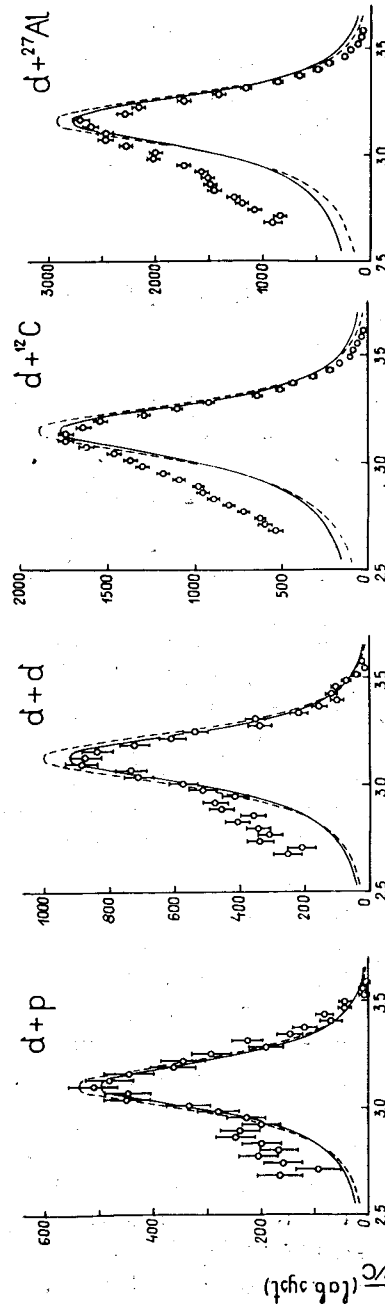
Secondaries emitted at an angle of 103 mrad were analyzed by a one-arm magnetic spectrometer (momentum resolution of ± 0.25%) on-line with a computer. The particle tracks were fixed before and behind the magnet by means of double-coordinate wire spark chambers K1,..., K11 [10]. A spark chamber system trigger required the coincidence of scintillation counters $C_1,...,C_4$. The angular divergence of the picked secondary beam was defined by the entrance counter C_1 amounting to ±1.7 mrad. The spectrometer momentum acceptance was equal to ±15% covering the measured momentum interval from 2.6 to 3.6 GeV/c. The geometrical efficiency of the spectrometer was amounted to 100% for the most part of the momentum interval, and only close to the interval boundaries the efficiency fell to about 60%.

Proton spectra for d-p and d-d collisions were obtained by subtracting the spectra from CH_2, CD_2 and C targets equivalent in stopping powers. Secondary deuterons in the interval from 2.6 to 3.6 GeV/c clearly separated from protons in the data analysis by a calculation of particle mass based on the measured momentum and 20 meter time-of-flight between counters C_0 and C_4. The ratio of the deuteron and proton yields integrated over the 2.6-3.6 GeV/c interval was amounted approximately to 1.1% for all the investigated collisions.

The data were corrected for "target out" background (typically amounting to about 3%), accidental coincidences (~4%), nuclear absorption and multiple Coulomb scattering along the spectrometer (~4%), and geometrical inefficiency of the spectrometer close to the momentum interval boundaries. The possible systematic error of the measured differential cross sections $d^2\sigma/d\Omega\, dp$ due to the uncertainties in the absolute beam monitoring, in the defining of the spectrometer solid angle and in the calculation of the above mentioned corrections is estimated to be ±20%.

The experimental results are shown in fig.2. Proton peaks with the maxima at about 3.1 GeV/c and 280-300 MeV/c FWHM dominate in all the measured spectra. The intense yield of protons with momenta that are approximately equal to one-half of the incident deuteron momentum is apparently due to the deuteron break-up processes. On the left-hand side of the proton peak for d-p collisions, starting from 2.9 GeV/c, a distinctive shoulder is visible showing that the deuteron break-up is accompanied sometimes by the pion production. With increasing A the left-hand sides of the proton peaks become more enriched with protons that have lost some energy in the inelastic interactions.

The width of the angular distribution of spectator nucleons from the stripping and the coherent diffractive dissociation should amount to about 15 mrad at 6.3 GeV/c. Therefore, one may believe that protons from quasielastic p-p or exchange n-p scattering of one of the deuteron nucleons on the target nucleon rather than spectator protons were mostly observed in the present experiment. Such a quasielastic N-N scattering may take place both in the stripping and in the in-



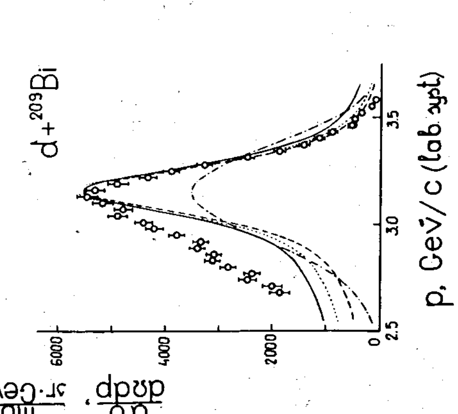


Fig.2.Momentum spectra of protons emitted at an angle of 103 mrad (lab system) in the collisions of 6.3 GeV/c deuterons with the H, D C, Al, and Bi nuclei. The solid lines represent the calculations with the Reid wave function, the dashed lines are the same with the Moravcsik Gartenhaus wave function.The results of calculations with the Hulthen wave function (dotted line) and with the Gaussian wave function (dash-dot line) are shown for d-Bi collisions.

coherent dissociation of deuterons, and it has to be accompanied by some momentum loss of the scattered proton. When a 3.15 nucleon is scattered at an angle of 103 mrad this momentum loss amounts to approximately 50 MeV/c.

Recently the process (1) has been considered by Bertocchi and Treleani [11] within the framework of the Glauber multiple scattering model taking into account the relativistic deformation of the deuteron wave function. We have used the expression derived by them to describe the experimental results obtained in the present work.

According to ref. [11] the differential cross section for the emission of fast protons in the reaction (1) may be written in the form

$$\frac{d^2\sigma}{d\Omega\, dp} = C_d \frac{E^* p^2}{E} \{ \phi_d^2(\vec{t}_p, \ell_p)\sigma_t - 2\phi_d(\vec{t}_p, \ell_p) \times \times \int \phi_d(\vec{q}, \ell_p) \frac{d\sigma(\vec{t}_p - \vec{q})}{d\vec{q}} d^2q + \int \phi_d^2(\vec{q}, \ell_p) \frac{d\sigma(\vec{t}_p - \vec{q})}{d\vec{q}} d^2q \}, \qquad (2)$$

where C_d is the normalizing factor, σ_t is the total nucleon-nucleus cross section, $d\sigma(q)/dq$ is the differential cross section for the elastic plus quasielastic proton-nucleus scattering, t_p and ℓ_p are the transverse and longitudinal components of the proton momentum p before the scattering act, E^* and E are the energies of a proton with the momenta p^* and p, respectively. The deuteron wave function $\phi_d(t_p, \ell_p)$ is computed at the value of the momentum p^* in the deuteron rest frame that is connected with t_p and ℓ_p through the relation

$$ME^* = E_d\sqrt{k_d^2 + t_p^2 + \ell_p^2 - 2k_d\ell_p + m^2} + k_d\ell_p - k_d^2, \qquad (3)$$

where m and M are the proton and deuteron masses, respectively, k_d and E_d are the incident deuteron momentum and energy.

The cross sections σ_t and $d\sigma(q)/dq$ at 3.15 GeV/c have been computed according to ref. [12], the N-N scattering amplitude being taken in the form

$$f(q) = \frac{(i+\rho)k\sigma}{4\pi}\exp\left(-\frac{1}{2}bq^2\right), \qquad (4)$$

where $\sigma = 43.6$ mb, $\rho = -0.43$, $b = 6.7\,(\mathrm{GeV}/c)^{-2}$. For the C, Al and Bi nuclei the Woods-Saxon nuclear density distribution has been used with the parameters given in refs. [12,13]. For the p-d scattering the values of $d\sigma(q)/dq$ have been computed according to ref. [14].

Thus obtained the proton-nucleus differential cross sections as functions of the momentum transfer have been approximated by the sum of the two Gaussian distributions

$$\frac{d\sigma(q)}{dq} = \frac{\sigma_1 B_1}{\pi}\exp(-B_1 q^2) + \frac{\sigma_2 B_2}{\pi}\exp(-B_2 q^2). \qquad (5)$$

The accuracy of this approximation was within the range of 10%. Parameters of eq. (5) for

the various nuclei are given in the table.

Table

Parameters of eq. (5).

A	σ_1, mb	B_1, $(\mathrm{GeV}/c)^{-2}$	σ_2, mb	B_2, $(\mathrm{GeV}/c)^{-2}$
H	18.0	6.7	-	-
D	16.2	25	30	3.8
C	116	57	50	6.2
Al	232	109	94	6.05
Bi	1320	400	178	6.0

The deuteron wave function has been approximated by: (a) the multi-Gaussian representation of the Reid soft-core wave function [15]; (b) the fit of Moravcsik to the Gartenhaus wave function [16]; (c) the Hulthen wave function with the parameters: $\alpha = 0.232\,\mathrm{fm}^{-1}$, $\beta = 1.202\,\mathrm{fm}^{-1}$; (d) the Gaussian wave function with the value of the deuteron radius $R_d = 2.28$ fm.

In ref. [11], to seek for an agreement with the experimental data obtained at Berkeley [8] for Be, C, and Pb nuclei under the conditions that the square of the four-momentum transfer in the N-N scattering $|t_{NN}|$ amounted only to 0.006 or 0.016 $(\mathrm{GeV}/c)^2$, it was necessary to calculate normalizing factors C_d for every computed spectrum, which were found to be considerably smaller than unity. Since in the present experiment

$|t_{NN}| \simeq 0.104\ (GeV/c)^2$, and therefore, the effect of the final-state interaction between the nucleons from the broken deuteron should be less singificant, it proved to be possible to take the normalizing factors to be equal to unity within the range of 10%.

The results of our calculations are given in fig.2. The comparison with the experimental data shows that the right-hand sides of the proton peaks are reasonably reproduced by the distributions calculated with the Reid and Moravcsik-Gartenhaus wave functions. The distributions obtained with the Hulthen wave function (the result is shown only for the Bi nucleus) have a similar behaviour as well. On the contrary the calculations with the Gaussian wave function that are again shown only for the Bi nucleus are in poor agreement with the experimental data. Near the upper boundary the distributions calculated for the C, Al, and Bi nuclei are only in qualitative agreement with the proton experimental spectra.

In the model under consideration /11/ the width of the proton peaks is defined essentially by the momentum distribution of the nucleons inside the deuteron taking into account the Lorentz dilation when one goes over from the deuteron rest frame to the laboratory frame. The prediction of the model about the weak sensitivity of the width of the proton peaks to A is in general confirmed by the present experiment.

Another property of the model is that it lays no claim to the description of the left-hand sides of the proton peaks where the effects due to the pion production by the nucleons of the incident deuteron are exhibited.

In order to estimate the cross sections corresponding only to the quasielastic scattering of the deuteron nucleons on the target nucleons, the distributions computed with the Reid wave function were integrated over the proton momentum within the limits from 2.5 to 3.6 GeV/c. The values of differential cross sections thus obtained are (176 ±16), (328 ±20), (700 ±25), (1085 ±50) and (2430 ± ±140) mb/sr for the H, D, C, Al, and Bi nuclei, respectively. For all the nuclei, except for hydrogen, the values can be approximated by the dependence

$$\frac{d\sigma}{d\Omega} = (240 \pm 6)\, A^{0.44 \pm 0.01}\ \mathrm{mb/sr}.$$

Thus, the measured momentum distributions of protons resulting from the 6.3 GeV/c deuteron break-up on H, D, C, Al, and Bi nuclei are, on the whole, reasonably reproduced within the framework of the multiple scattering model. The width of the proton peaks turns out to be well explained taking into account the Lorentz dilation of the incident deuteron wave function. At the same time it is worth noting that new experiments are desirable. It would be interesting to investigate the deuteron fragmentation processes at different angles, and to perform the measurements in the range of the higher momenta of the secondary protons.

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