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Структура высокоимпульсных частей спектров дейтронов от d – d соударений при 4,3; 6,3 и 8,9 ГэВ/с

Представлены экспериментальные данные о d–d соударениях при 4,3; 6,3 и 8,9 ГэВ/с, обнаруживающие двухпиковую структуру в высокоимпульсных частях спектров вторичных дейтронов при передачах импульса 0,4÷0,8 $(ГэВ/с)^2$. Результаты анализируются в рамках модели многократного нуклон–нуклонного рассеяния. Делаются заключения о механизме упругого и квазиупругого d–d рассеяния в области указанных передач импульса.

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The Structure of the High-Momentum Parts of the Deuteron Spectra from d – d Collisions at 4.3, 6.3 and 8.9 GeV/c

The experimental data on d–d collisions at 4.3, 6.3 and 8.9 GeV/c exhibiting the two-peak structure in the high-momentum parts of the secondary deuteron spectra at momentum transfers $|t| \sim 0.4 \div 0.8$ (GeV/c) are presented. An analysis of the results in terms of the multiple nucleon-nucleon scattering model is performed. Some conclusions about the mechanism of the elastic and quasi-elastic d–d scattering at the above-mentioned momentum transfers are made.

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

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The experimental and theoretical investigations performed in the last years have shown that the multiple scattering model[1,2] has been successful in describing the scattering of relativistic hadrons on nuclei at four-momentum transfers $|t| \leq 1.5\ (GeV/c)^2$. From the point of view of a possible generalization of this model to the case of the interaction of complex composite systems, the investigations of deuteron-deuteron and deuteron-nucleus collisions are of great interest. In this case such kinds of multiple N-N scattering can take place that are, in principle, impossible in nucleon-nucleus collisions, and that are due to the simultaneous interaction of several nucleons of an incident nucleus with the nucleons of a target nucleus[3].

It has been previously reported [4] that in the momentum spectrum of deuterons emitted at an angle of 103 mrad in the process

$$d + d \to d + X \qquad (1)$$

at 6.3 GeV/c, two distinct peaks are observed, which can be interpreted as an exhibition of the multiple N-N scattering effect. In this paper we present the results of measurements of high-momentum parts of secondary deuteron spectra from d-d collisions at 4.3, 6.3 and 8.9 GeV/c as well as the results of an analysis of these spectra in terms of the multiple scattering model.

The experimental data were obtained during the course of a series of measurements of nuclear interactions of relativistic deuterons at the JINR synchrophasotron. The secondary deuterons emitted in reaction (1) were detected at a fixed angle of 103 mrad by means of an one-arm magnetic spectrometer with wire spark chambers on-line with a computer. The details of the spectrometer and the experimental technique have been outlined in previous publications [4-6]. The possible systematic error of the measured differential cross sections $d^2\sigma/d\Omega\, dp$ is estimated to be $\pm$ 20%.

The high-momentum parts of the deuteron spectra from reaction (1) for three values of incident deuteron momenta are shown in fig.1. The investigated regions of momentum losses correspond to the elastic and quasi-elastic (with the target deuteron break-up) $d-d$ scatterings. In the case of 4.3 GeV/c deuteron scattering there is a peak seen in the spectrum with a bump visible on the right-hand side of it showing that there is another weak peak, the position of which corresponds to approximately a twice smaller incident deuteron momentum loss than for the first peak. At 6.3 and 8.9 GeV/c both of the peaks are well separated and become compared in heights. In all the spectra the positions of the left-hand peaks correspond kinematically to the deuteron scattering on nucleons, and the positions of the right-hand peaks correspond to the elastic deuteron scattering on deuterons.

The obtained data were analysed in the framework of the Glauber multiple scattering model. Without going into details of the calculations which will be presented elsewhere we note only the most essential points that differ the present calculations from that of the proton spectra from the reaction

$$p + d \to p + X, \qquad (2)$$

which was investigated at the incident proton momenta of about 20 GeV/c [7-11].

1. First of all the amplitude of reaction (1) is more complicated. It includes the terms correspond-

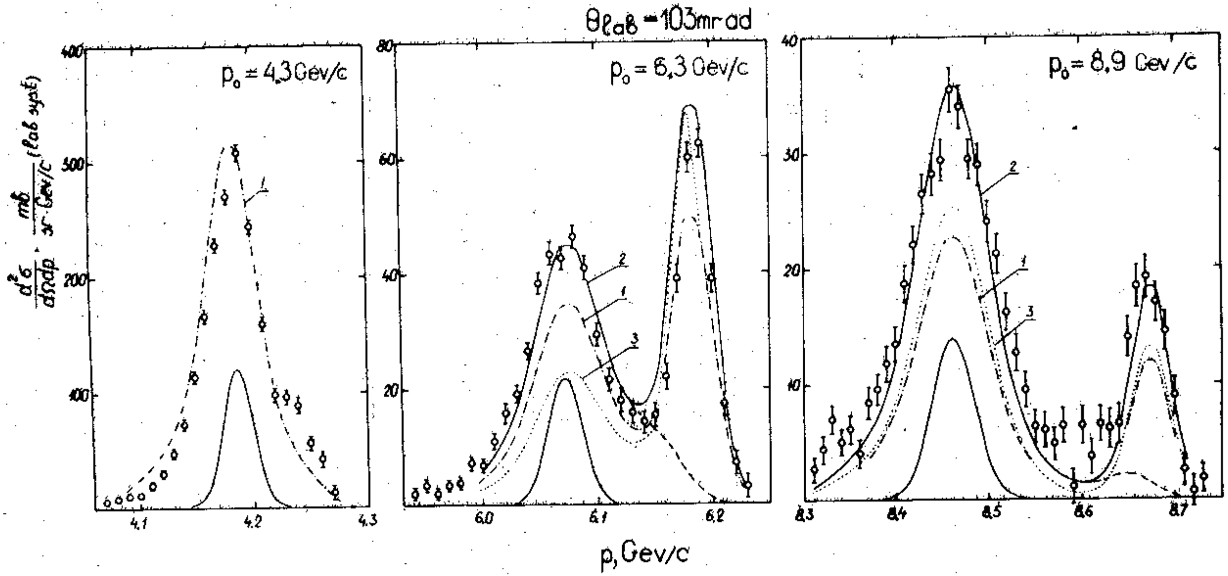

Fig. 1. Momentum spectra of deuterons detected at a laboratory angle of 103 mrad in d-d collisions at 4.3, 6.3 and 8.9 GeV/c. Curves 1,2 and 3 are the variants of the calculations based on the multiple scattering model with the input parameters given in table 1. The dashed curves show the calculated contributions from the quasi-elastic deuteron scattering to the peaks corresponding kinematically to the elastic d-d scattering. The solid curves without figures are the elastic d-p scattering peaks multiplied by a factor 0.3; these characterize the spectrometer resolution.

ing to the N-N scattering processes of various multiplicities that are schematically represented in fig.2. Various kinds of multiple N-N collisions lead to the deuteron momentum loss distributions which have the maxima at different momentum loss values. The scattering of one (fig.2a) or both incident nucleons (fig.2b) on one of the deuteron nucleons leads to the momentum loss $\Delta \simeq (p_0 \theta)^2/(2m)$, where p_0 is the incident deuteron momentum, θ is a scattering angle and m is a nucleon mass. The successive scattering of one of the incident nucleons on both target nucleons (fig.2c), or the simultaneous scattering of both incident nucleons each on one of two target nucleons (fig.2d), as well as the quadruple N-N scattering (fig.2g) lead to the loss of about $\Delta/2$; the triple N-N scatterings (figs. 2e and f) give rise to momentum losses distributed smoothly around the value of about $5\Delta/8$. Therefore, the parts of spectra corresponding kinematically to the elastic $d-d$ scattering (deuteron momentum losses of about $\Delta/2$) can be contributed, in addition to the elastic scattering, by the quasi-elastic scattering due to the double and quadruple N-N collisions. As it follows from the calculations, at the momentum transfers greater than about 1.2 $(GeV/c)^2$ the three-peak structure of the high-momentum parts of the deuteron spectra in reaction (1) must exhibit. The destructive character of the interference of the terms in the reaction amplitude, which correspond to the even and odd multiplicities of N-N collisions, helps to separate the peaks.

2. Because of the sensitivity of the shape of the quasi-elastic scattered deuteron spectra to the momentum distribution of nucleons in the target deuteron, a more precise parametrization of the deuteron wave function was required. In the present calculations a two-Gaussian parametrization of the deuteron wave function in the momentum space was used:

$$\Psi(p) = N[3\exp(-\alpha_1 p^2) + \exp(-\alpha_2 p^2)],$$

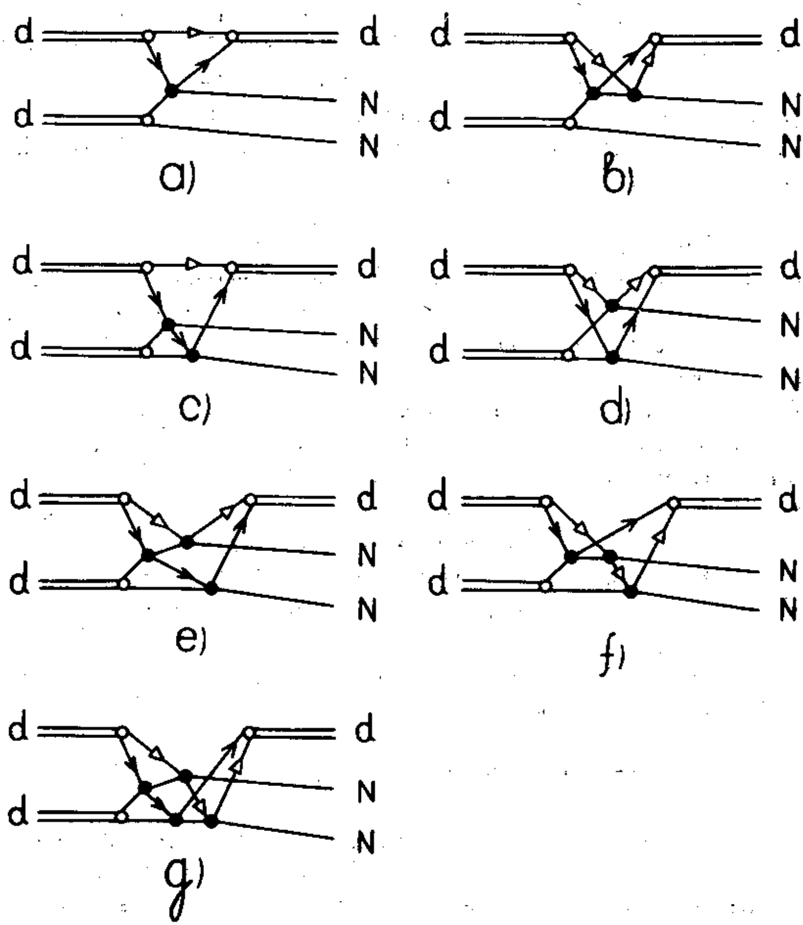

Fig. 2. Schematic representation of the multiple nucleon-nucleon scattering processes resulting in the quasi-elastic d–d scattering (in which the target deuteron is disintegrated). Graph a) represents single, graphs b), c) and d) - double, graphs e) and f) - triple, and graph g) - quadruple N-N scatterings.

where $N = 9.80\ (\mathrm{GeV/c})^{-3/2}$, $a_1 = 450\ (\mathrm{GeV/c})^{-2}$, $a_2 = 50\ (\mathrm{GeV/c})^{-2}$. The function $\Psi(p)$ coincides with the Gartenhaus-Moravcsik III function [12] and with a five-Gaussian representation of the Reid soft-core wave function [13] within 15% up to $p \simeq 0.25$ GeV/c. The use of the simplified one-Gaussian approximation of the deuteron wave function [9] did not permit the correct ratio between the yields of the quasi-elastic and elastic scattered deuterons to be obtained.

3. It follows from the calculations, that the main contribution to the peak at the deuteron momentum loss of $\Delta/2$ in reaction (1), unlike reaction (2), is made not by the quasi-elastic but elastic d–d scattering. Therefore the neglect of the final-state interaction in the n–p system and the use of the plane-wave approximation to describe it are unjustified. The interaction in the n–p system resulting from the deuteron disintegration was taken into account by means of the replacement of the plane waves with the modified plane waves which are orthogonal to the wave function of the deuteron ground state [14].

In the calculations the elastic N–N scattering amplitude has been taken in the form

$$f(t) = \frac{k\sigma}{4\pi}(i+\alpha)\exp(\frac{1}{2}bt),$$

where k is a wave number of the incident nucleon, t is a four-momentum transfer squared, $\alpha = \mathrm{Re}f(0)/\mathrm{Im}f(0)$, σ is a total N–N cross section, and b is a slope parameter for the differential cross section of the elastic N–N scattering. The values of the parameters σ, α and b for the appropriate values of the incident nucleon momenta have been taken from the compilation of N–N interaction data [15]. As the slope parameters b in the momentum interval from 2 to 5 GeV/c are known only with an accuracy of 10 ÷ 15%, and in order to check the sensitivity of the calculation results to the used values of the parameters, several variants of the calculations with different α and b values were performed. These values are given in table 1, and

Table 1

The values of the parameters of the elastic N-N scattering amplitude used in different variants of the calculations

p_0, GeV/c	σ, mb	α	b, $(GeV/c)^{-2}$	Variant of calculat.
4.3	45.0	-0.35	5.9	1
6.3	43.5	-0.43	7.2	1
	43.5	-0.43	5.7	2
	43.5	0	5.7	3
8.9	42.4	-0.43	7.3	1
	42.4	-0.43	6.3	2
	42.4	0	6.3	3

the calculation results are shown in fig.1. It is seen, that the used model has been successful in the qualitative describing of the main features of the measured momentum distributions. Keeping in mind the uncertainty in the values of the input parameters to which the calculation results are rather sensitive and also the approximations of the used model, the quantitative agreement of some calculation variants with the experimental data should not be overestimated. The obtained results may be regarded as an indication that in case of using a sufficiently accurate version of the multiple scattering model it is possible to obtain the information about the ratio of real and imaginary parts of the elastic N-N scattering amplitude out of the region of the Coulomb-nuclear interference from the d-d collision data.

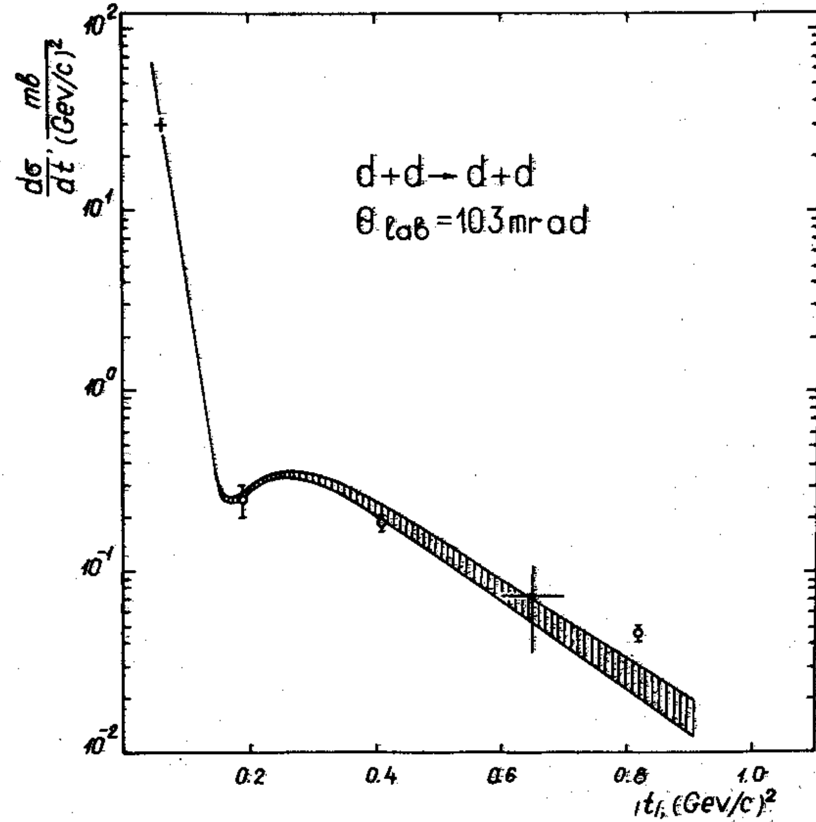

Fig.3. Differential cross section for the elastic d-d scattering at a laboratory angle of 103 mrad. The crosses show the results from ref. [16], and the open cirles show the data from the present experiment. The solid curves are the results of the calculation in terms of multiple scattering model [17], the shaded area reflects the uncertainties in the experimental values of the slope parameters in the elastic N-N scattering amplitude.

By means of subtracting the contributions of the quasi-elastic scattering corresponding to the calculation variants that describe the experimental data in the best way from the measured deuteron distributions, the values of the differential cross sections for the elastic d-d scattering at an angle of 103 mrad were determined for the incident deuteron momenta of 4.3, 6.3 and 8.9 GeV/c. These values are given in table 2.

Fig. 3 shows the differential cross sections for the elastic d-d scattering at an angle of 103 mrad plotted in terms of |t| , the square of the four-momentum transfer. In addition to the data obtained in the present work the data from ref.[16] are shown as well. The theoretical calculations of this dependence were carried out in terms of the Glauber model taking into account the quadrupole deformation of a deuteron[17]. The shown corridor of errors reflects the uncertainties in the experimental values of the slope parameters of the elastic N-N scattering amplitudes[15].

To conclude we underline that the revealed structure of the high-momentum parts of the spectra of the elastic and quasi-elastic scattered deuterons is a new object to check the predictions of the multiple scattering model, which without any additional assumptions reproduces qualitatively the main features of the measured deuteron distributions. The obtained

Table 2

The differential cross sections for the elastic and quasi-elastic (with the target deuteron break-up) d-d scatterings at a laboratory angle of 103 mrad, in mb/sr

p_0, GeV/c	$(\frac{d\sigma}{d\Omega})_{el}$	$(\frac{d\sigma}{d\Omega})_{quasiel}$	$(\frac{d\sigma}{d\Omega})_{summed}$
4.3	1.4±0.3	19.3±0.5	20.7±0.5
6.3	2.2±0.1	4.5±0.3	6.7±0.3
8.9	1.1±0.1	4.4±0.3	5.5±0.3

results permit certain conclusions to be made about the mechanism of the elastic deuteron scattering in the range of momentum transfers $|t| \sim 0.3 \div 1.0 (GeV/c)^2$. This scattering occurs, in the main, by means of such double scatterings when in simultaneous collisions both the nucleons of the incident deuteron scatter each on one of the two target nucleons (fig.2d). Such a mechansim of the elastic d-d scattering allows rather great momentum transfers to both the deuteron nucleons at their small relative momentum.

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