Parameters of the six-quark component of the deuteron

V. G. Ableev[1], G. G. Vorob'ev, L. Vizireva[2], Kh. Dimitrov[3], S. A. Zaporozhets, A. P. Kobushkin[4], D. K. Nikitin[5], A. A. Nomofilov, N. M. Piskunov, I. M. Sitnik, E. A. Strokovskii, L. N. Strunov, A. Filipkowski[6], and V. I. Sharov
Joint Institute for Nuclear Research

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New data are reported on the momentum distribution of the nucleons in the deuteron. The parameters of the six-quark component of the deuteron are determined. The use of this component leads to a good description of accurate data on deuteron stripping by nuclei (from Dubna) and on the electrodisintegration of deuterons (from Stanford).

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1. Our data on the momentum spectra of the protons emitted at a zero angle during the fragmentation of relativistic deuterons (8.9 GeV/c) by nuclei, obtained on the JINR proton synchrotron, were reported in Refs. 1 and 2 (preliminary results have been reported at international conferences[3]). These spectra can be used to find the momentum distribution of the nucleons in the deuteron, through the use of an expression derived by a relativistic approach:[4]

$$E\, d^3\sigma / d\mathbf{p} = \frac{1}{8\pi} \sigma_{NA}^{in} \frac{\sigma_{dA}^{in}}{\sigma_{dA}^{T}} \sqrt{\frac{m^2}{4\alpha(1-\alpha)^3}}\; F(\alpha) |\psi(k^2)|^2 . \tag{1}$$

Here σ_{dA}^{in} and σ_{NA}^{in} are the total inelastic cross sections for dA and NA interactions; σ_{dA}^{T} is the total dA cross section; $k^2 = (m^2 + p_\perp^{*2})/[4\alpha(1-\alpha)] - m^2$; α is the light-front variable, given by $\alpha = (E_p^* + p_\parallel^*)/M_d$; M_d and m are the masses of the deuteron and the proton; p^* is the momentum of the spectator proton in the rest frame of the deuteron; and $\psi(k^2)$ is the overlap integral of the deuteron wave function and the unbound np state (which is the same as the deuteron wave function in the momentum

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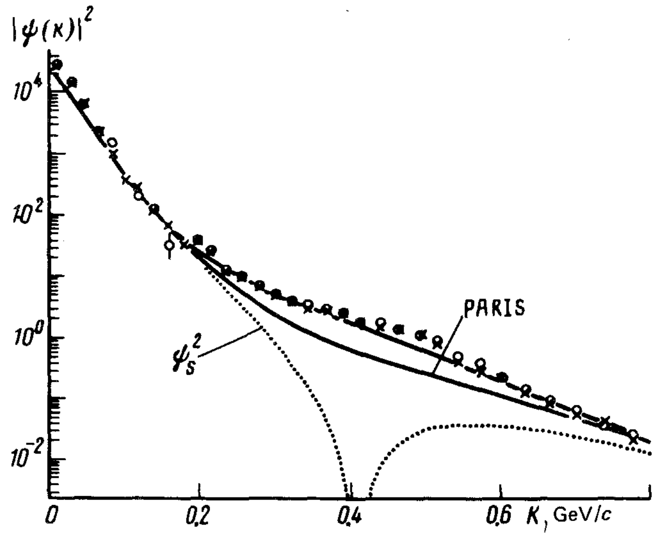

FIG. 1. Momentum distributions of the nucleons in the deuteron. x–Carbon target; ○–polyethylene target. The statistical errors are indicated if they exceed the dimensions of the symbols. PARIS–Square of the PARIS-potential deuteron wave function; ψ_S^2–contribution of the S-wave component of the PARIS deuteron wave function; upper curve–our deuteron wave function with the parameters given in the text proper. The data for k from 0.36 to 0.53 were ignored in the determination of these parameters, since the discrepancy between those data and our deuteron wave function may be caused by a contribution from the diffraction production of a dibaryon resonance.[1,2]

representation if we assume that the deuteron is simply a two-nucleon system). We are using the same normalization of the deuteron wave function as in Ref. 8. The factor $F(\alpha)$ was introduced in Ref. 4 to reflect kinematic limitations on the reaction phase volume. In determining the momentum distribution of the nucleons in the deuteron we confined the consideration to the region $k \lesssim 0.8$ GeV/c, since at $k > 0.8$ GeV/c this factor begins to fall off rapidly as we approach the kinematic limit for the reaction under study, $d + A \to p + X$. Furthermore, in this region, near $k \cong 1.02$ GeV/c, there may be contributions from other mechanisms which involve the ejection of a proton from the target: $dp \to pd$, $dp \to p(np)$.

Figure 1 shows the momentum distribution of the nucleons in the nucleon obtained with the help of (1) from the data obtained from targets with various neutron and proton compositions (carbon and polyethylene).

Despite the different isospin compositions of the targets, the momentum distributions of the nucleons are essentially the same over the entire measurement range. This agreement is evidence that the final-state interaction effects depend only weakly on the isospin. Actually, the primary mechanism leading to this type of final-state interaction is the excitation of the isobar in an intermediate state; its contribution decreases by a factor of nearly five as we switch from a proton target to a neutron target.[5] Noting that the effective number of nucleons in carbon is about six, we discard the hypothesis of final-state-interaction effects of this sort on the basis of the χ^2 test at a significance level of 1%.

In the high-momentum region (for k from 0.2 to 0.6 GeV/c), where $|\psi(k^2)|^2$ falls off by three to five orders of magnitude, we find that the measured values of $|\psi(k^2)|^2$ exceed the values expected on the basis of the known deuteron wave functions (including the most recent Paris-potential deuteron wave function[6]) by up to 300–400% (Fig. 1).

Taking into account the arguments against an important role of final-state-interaction effects sensitive to the target isospin, we have offered an explanation of this discrepancy[1–3] based on the hypothesis[7] of an S-wave contribution of a six-quark state of the deuteron ($6q$) to the total deuteron wave function. When we take into account this contribution,

$$\frac{|\psi(k^2)|^2}{4\pi} = (1-\beta^2)\,\psi_{np}^2(k^2) + \beta^2\,\psi_{6q}^2(k^2) + 2\beta(1-\beta^2)^{1/2}\cos\kappa\,\psi_{np}(k^2)\,\psi_{6q}(k^2), \tag{2}$$

where

$$\psi_{6q}(k^2) = \frac{1,36}{\sqrt{2}}(8r_{6q}^2/15\pi)^{3/4}\exp(-4r_{6q}^2k^2/15), \tag{3}$$

we find equally successful descriptions of the data of Refs. 1 and 2 (Fig. 1). The parameters of the $6q$ component were estimated[7] in Ref. 1: $r_{6q} = 0.95 \pm 0.05$ F, $\beta^2/2 = 0.043 \pm 0.004$, and $\kappa = 82 \pm 6^\circ$ at χ^2/(degrees of freedom) = 1.9 [if $6q$ is not used, the value is χ^2/(degrees of freedom) $\cong 16$]. Within the errors, these estimates agree with the estimates from the data of Ref. 2. As $\psi_{np}(k^2)$ we used the PARIS deuteron wave function and carried out the analysis in the relativistic Glauber theory.

2. A comparison of our results with data on the electrodisintegration of the deuteron became possible after the SLAC group analyzed[8] its earlier data and data obtained by other groups, including the Khar'kov group.[9] The purpose of that analysis was again to extract information about the momentum distribution of the nucleons in the deuteron. Bosted *et al.*[8] presented their results as a function of the variable k,

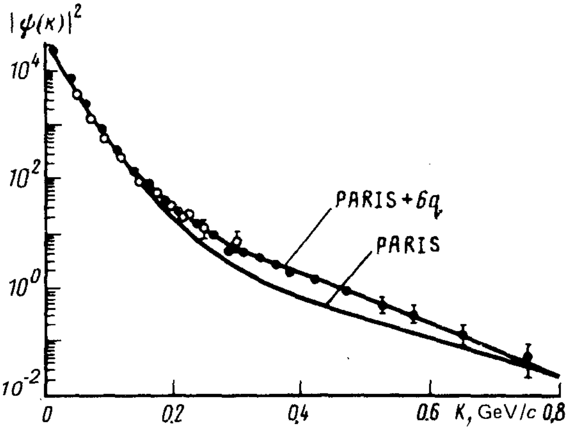

FIG. 2. Momentum distribution of the nucleons in the deuteron found in Ref. 8: ●–SLAC data; ○–data from Ref. 9. PARIS + $6q$–Our deuteron wave function.[1,2]

which they call the momentum of the spectator nucleon p^*; in the nonrelativistic case, and in their kinematics, these quantities are in fact the same.

Figure 2 shows the results of this analysis. Bosted *et al.*[8] also pointed out the discrepancy between the measured momentum distribution of the nucleons and the PARIS deuteron wave function. They maintain that this discrepancy cannot be explained on the basis of a final-state interaction.

Figure 2 shows our deuteron wave function in the form in (2) along with the parameters of the $6q$ component, given earlier. We see that this wave function gives a good description of the SLAC data without any additional fit.

3. In summary, the momentum distributions obtained for the nucleons in the deuteron do not depend on the measurement method: electrodisintegration of the deuteron at electron energies from 6 to 21 GeV and Q^2 values from 0.8 to 10 GeV^2/c^2 or fragmentation of a relativistic deuteron by nuclear targets (with various numbers of neutrons and protons), with emission of a nucleon at a zero angle. The discrepancy observed between the momentum distribution of the nucleons and the PARIS deuteron wave function can be interpreted in a natural way as a manifestation of a multiquark component of the deuteron, in the spirit of the current understanding.[7,10]

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[1)]Scientific-Research Institute of Nuclear Physics, Moscow State University, Moscow.
[2)]VKhTI, Sofia, People's Republic of Bulgaria.
[3)]TsLANP, Bulgarian Academy of Sciences, Sofia, People's Republic of Bulgaria.
[4)]Institute of Theoretical Physics, Academy of Sciences of the USSR, Kiev
[5)]Physicotechnical Institute, Academy of Sciences of the Tadzhik SSR, Dushanbe.
[6)]Institute of Nuclear Physics, Warsaw, Polish People's Republic.

[9)]A factor of $1/\sqrt{2}$ was omitted from the expression for $\psi 6q$ in Eqs. (12) and (17) in Ref. 4. The size of the $6q$ admixture found in Refs. 1 and 2 should therefore be doubled.

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