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Novel Hadron Physics by Structure Functions of Spin-1 Hadrons

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There are new polarized structure functions, which do not exist for the spin-1/2 nucleons, in a spin-1 hadron such as the deuteron. In the charged-lepton deep inelastic scattering, the new leading-twist structure functions are b_1 and b_2, which are related by the Callan-Gross type relation $b_2 = 2xb_1$ in the Bjorken scaling limit. There exists a parton-model sum rule for b_1 [1]. We theoretically calculated b_1 by using the standard convolution model for the deuteron with D-state admixture [2], and we obtained a very different distribution from HERMES data. This fact indicates that a new hadron-physics mechanism could be needed to explain the large difference. This topic will be investigated at the Jefferson Laboratory, and also at hadron accelerator facilities such as Fermilab by the proton-deuteron Drell-Yan process [3] and the nuclotron-based ion collider facility (NICA) by the J/ψ production [4].

Second, the gluon transversity is a new and interesting distribution in the spin-1 deuteron. Although there was recent experimental progress on quark transversity distributions, there is no experimental information on the gluon transversity. The gluon transversity does not exist for the spin-1/2 nucleons due to the helicity-conservation constraint. One needs a hadron with spin more than or equal to one, so that the helicity flip of two units is allowed. In our work, we proposed the possibility for finding the gluon transversity at hadron-accelerator facilities, especially in the proton-deuteron Drell-Yan process, by showing theoretical formalism and numerical results [5]. Since the internal spin-1/2 nucleons within the deuteron cannot contribute directly to the gluon transversity, it is a good observable to find a new non-nucleonic component beyond the simple bound system of nucleons in nuclei.

Third, we explain possible transverse-momentum-dependent parton distribution functions (TMDs) for spin-1 hadrons up to twist 4 by decomposing a quark correlation function with the conditions of the Hermiticity and parity invariance [6]. We found 30 new structure functions in the twist 3 and 4 in our work. Since time-reversal-odd terms of the collinear correlation function should vanish after integrals over the partonic transverse momentum, we obtained new sum rules for the time-reversal-odd structure functions, $\int d^2k_T g_{LT} = \int d^2k_T h_{LL} = \int d^2k_T h_{3LL} = 0$. In addition, we indicated that new fragmentation functions exist in tensor-polarized spin-1 hadrons. Integrating the TMDs over the transverse momentum, we found new collinear PDFs for spin-1 hadrons. For these PDFs, we showed that a twist-2 relation and a sum rule exist for the tensor-polarized parton distribution functions f_{1LL} and f_{LT} [7]. Furthermore, we indicated that four twist-3 multiparton distribution functions F_{LT}, G_{LT}, $H_{LL}^{\perp}$, and H_{TT} exist for tensor-polarized spin-1 hadrons.

In the near future, we expect that physics of spin-1 hadrons will become a popular topic, since there are experimental projects to investigate spin structure of the spin-1 deuteron at the Jefferson Laboratory, the Fermilab, the NICA, the LHCspin, and the electron-ion colliders in US and China in 2020's and 2030's.

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