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Research Article

STATISTICAL EVALUATION OF FIRST AND SECOND MOMENTS OF QUARK AND ANTI-QUARK HELICITY

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ABSTRACT

We evaluate quark helicity distribution inside a nucleon in the kinematic region $0.02 < x < 0.6$ at $Q^2 = 2.5\ GeV^2$ and first and second moment of polarized valence up and valence down quark using Thermodynamical Bag Model (TBM). Theoretical results are in good agreement with HERMES and SMC experimental results.

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INTRODUCTION

The understanding of the nucleon spin structure is a fundamental challenge in hadronic physics. Since it was demonstrated by EMC[1], deep inelastic scattering (DIS) studies provide about quark-gluon structure of the nucleon, it does not give the clear picture of the origin of its spin. Many experiments like SMC, HERMES and SLAC which are probed the spin structure of the nucleon [2-9] using inclusive measurements.

The presence of spin crisis has led to many different ideas on how to account for the nucleon spin. Recent inclusive polarized deep inelastic scattering have extended measurements of the nucleon spin structure function over a broad kinematic region where one is sensitive to scattering on the valence quarks and quarks-antiquarks sea fluctuations. These experiments have been interpreted to imply that quark and antiquark carry just a small fraction of the proton spin (15% - 35%) less than half the prediction of relativistic constituent quark model(60%). Non relativistic quark model overestimates the quark contribution of the nucleon spin. The quark spin contributes 25% of the proton spin and about 35% comes from the quark orbital angular momentum and 40% spin is due to the gluon. Orbital angular momentum of sea quarks to be small and the flavor independence of quark spin[10].

In a formal way, the nucleon spin can be written as

$$S_Z^N = S_Z^q + L_Z^q + J_Z^g = \frac{1}{2}$$

Where S_Z^N is the nucleon spin in which S_Z^q is combination of quark spin, L_Z^q is the orbital angular momentum of quarks and J_Z^g is the total angular momentum of gluon. In the present work, first we evaluate quark distribution inside a nucleon and hence obtained polarized valence up quark and valence down quark using thermodynamical bag model and the results are compared with HERMES [11] and SMC[12].

Thermodynamical Bag model

The DIS of lepton on nucleon indicates the nucleon consists of three valance quark, sea quark and gluon confined within a small volume. TBM is modified form of MIT bag model treat quark as fermions and gluon as Bosons, the invariant mass (W) the final hadron and the equation state[13-17] can be written as

$$\left[£(T)V + BV\right]^2 = W^2 = M^2 + 2M¬ - Q^2 \qquad (1)$$

$$6(n_u - n_{\bar{u}}) = \frac{2}{V} = «_u T^2 + \frac{«_u^3}{®^2} \qquad (2)$$

$$6(n_d - n_{\bar{d}}) = \frac{1}{V} = «_d T^2 + \frac{«_d^3}{®^2} \qquad (3)$$

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Where ε(T) is energy densities of the system at a temperature T, V volume of the Bag, B Bag constant, W mass of excited nucleon at temperature T, ¬ energy transfer, Q2 is the square of four momentum transfer, M nucleon mass at ground state $(n_u - n_{\bar{u}})$ number density of up quark $(n_d - n_{\bar{d}})$ number density of down quark, μ_u chemical potential of up quark and μ_d chemical potential of down quark, ε(T) is obtained for up quark, down quark and gluon as follows

$$£_u + £_{\bar{u}} = \left(\frac{1}{8®^2}\right)«_u^4 + \left(\frac{1}{4}\right)«_u^2 T^2 + \left(\frac{7®^2}{120}\right)T^4 \quad (4)$$

$$£_d + £_{\bar{d}} = \left(\frac{1}{8®^2}\right)«_d^4 + \left(\frac{1}{4}\right)«_d^2 T^2 + \left(\frac{7®^2}{120}\right)T^4 \quad (5)$$

$$£_g = \frac{®^2 T^4}{30} \quad (6)$$

The total energy density ε(T) of the bag can be written in terms of energy density of the constituents as,

$$£(T) = 6(£_u + £_{\bar{u}}) + 6(£_d + £_{\bar{d}}) + 16£_g \quad (7)$$

Where 6 is the degeneracy factor of quarks and 16 is the degeneracy factor of gluon. The unpolarized up and down quark distribution are expressed as

$$u(x,Q^2) = \left(\frac{6V}{4®^2}\right)M^2 Tx \ln\left\{1+\exp\left[\left(\frac{1}{T}\right)\left(«_u - \frac{Mx}{2}\right)\right]\right\} \quad (8)$$

$$d(x,Q^2) = \left(\frac{6V}{4®^2}\right)M^2 Tx \ln\left\{1+\exp\left[\left(\frac{1}{T}\right)\left(«_d - \frac{Mx}{2}\right)\right]\right\} \quad (9)$$

The antiquark distribution can be obtained by putting μ→ -μ

$$\bar{u}(x,Q^2) = \left(\frac{6V}{4®^2}\right)M^2 Tx \ln\left\{1+\exp\left[\left(\frac{1}{T}\right)\left(-«_u - \frac{Mx}{2}\right)\right]\right\} \quad (10)$$

$$\bar{d}(x,Q^2) = \left(\frac{6V}{4®^2}\right)M^2 Tx \ln\left\{1+\exp\left[\left(\frac{1}{T}\right)\left(-«_d - \frac{Mx}{2}\right)\right]\right\} \quad (11)$$

Polarized quark distribution function

The polarized structure functions can be obtained by multiplying the quark distribution functions with spin dilution factor $\cos 2¯(x)$.

$$\Delta u(x) = \left[(u(x)+\bar{u}(x)) - \frac{2}{3}(d(x)+\bar{d}(x))\right]\cos 2¯(x) \quad (12)$$

$$\Delta\bar{u}(x) = \left[(\bar{u}(x) - \frac{2}{3}\bar{d}(x)\right]\cos 2¯(x) \quad (13)$$

$$\Delta d(x) = \left[-\frac{1}{3}(d(x)+\bar{d}(x))\right]\cos 2¯(x) \quad (14)$$

$$\Delta\bar{d}(x) = \left[-\frac{1}{3}\bar{d}(x)\right]\cos 2¯(x) \quad (15)$$

The valence quark spin distribution functions are evaluated after modulating the quark distribution by the spin dilution factor.

$$\Delta u_V(x) = \left[(u(x)-\bar{u}(x)) - \frac{2}{3}(d(x)-\bar{d}(x))\right]\cos 2¯(x) \quad (16)$$

$$\Delta d_v(x) = \left[-\frac{1}{3}(d(x)-\bar{d}(x))\right]\cos 2¯(x) \quad (17)$$

Where

$$\cos 2¯(x) = \frac{1}{1+\left(\frac{H_0}{\sqrt{x}(1-x)^2}\right)}$$

is known as spin dilution factor[18] which vanishes as $x \to 0$ and becomes unity as $x \to 1$ characterizing the valence quark helicity contribution of proton. Since the spin dilution factor is derived from the first principles it is adjusted to satisfy the Bjorken sum rule which is considered as the fundamental test of QCD, this enable to determine explicitly. Here H_o is only free parameter which is used to satisfy the Bjorken sum rule. The unpolarized strange quark distribution function is obtain by addition of $\bar{u}$ and $\bar{d}$ which is given by

$$s(x) = \frac{1}{4}\left[\bar{u}(x) + \bar{d}(x)\right] \quad (18)$$

The polarized strange quark distribution function [19] is expressed as

$$\Delta s(x) = \frac{1}{3}\left[\Delta\bar{d}(x) - \Delta\bar{u}(x)\right] \quad (19)$$

The first and second moments of the helicity valence quark of distributions are given by

$$¦_{q_v} \equiv \int_0^1 x^{n-1}\Delta q_v(x,Q^2)dx \quad (20)$$

n = 1 is corresponding to the first moment which gives the

$$\int_0^1 \Delta q_v(x,Q^2)dx$$

The first moment of up and down quarks can be written as

$$¦_{u_V} = \int_0^1 u(x,Q^2)dx \quad (21)$$

$$¦_{d_V} = \int_0^1 d(x,Q^2)dx \quad (22)$$

n = 2 is corresponding to the second moment which gives the $\int_0^1 x\Delta q_v(x,Q^2)dx$

The second moment of up and down quarks can be written as

$$\text{¦}_{u_v} = \int_0^1 xu(x,Q^2)dx \quad (23)$$

$$\text{¦}_{d_v} = \int_0^1 xd(x,Q^2)dx \quad (24)$$

The first and second moments are evaluated in the region of 0.02 < x < 0.6 at Q2 = 2.5 GeV2. When n = 1, up quark distribution is merely equal to the down quark distribution at low x region whereas up quark distribution is more than the down quark distribution at high x region in the first moment. When n = 2, similar behavior is observed as the first moment evaluation. Theoretical evaluation of first moment is greater than the second moment which is due to the up quark dominating over than down quark distribution.

RESULTS AND DISCUSSION

In this present work, we evaluate the quark distribution inside a nucleon and first and second moment of polarized valence up and valence down quark using Thermodynamical Bag Model.

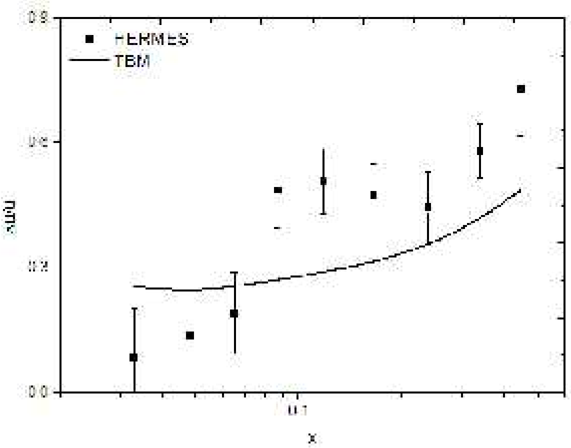

Figure 1 The up quark helicity distribution as a function of x at $Q^2 = 2.5$ GeV2. TBM results (solid line) are compared with HERMES experimental results (shaded squares).

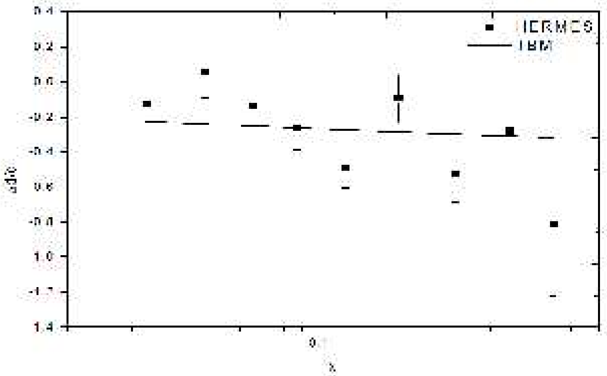

Figure 2 The down quark helicity distribution as a function of x at $Q^2 =$ 2.5 GeV2. TBM results (solid line) are compared with HERMES experimental results (shaded squares).

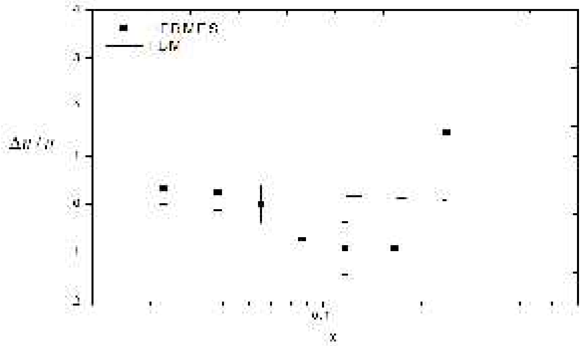

Figure 3 The anti-up quark helicity distribution as a function of x at $Q^2 =$ 2.5 GeV2. TBM results (solid line) are compared with HERMES experimental results (shaded squares).

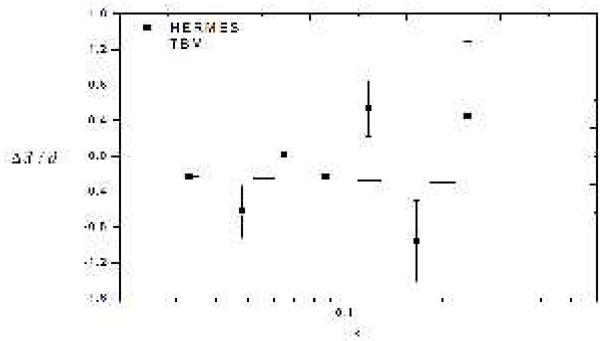

Figure 4 The anti-down quark helicity distribution as a function of x at $Q^2 = 2.5$ GeV2. TBM results (solid line) are compared with HERMES experimental results (shaded squares).

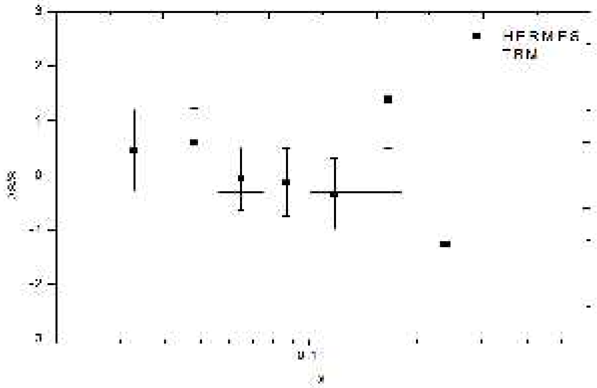

Figure 5 Strange quark helicity distribution as a function of x at $Q^2 = 2.5$ GeV2. TBM results (solid line) are compared with HERMES experimental results (shaded squares).

Figure 1 shows that the variation of $\Delta u / u$ with Bjorken variable. When x increases, $\Delta u / u$ reaches maximum value and further increasing x value, it decreases. Still $\Delta u / u$ is positive distribution which is due to up quark attains positive polarization. Figure 2 shows that the variation of $\Delta d / d$ with x. $\Delta d / d$ decreases with x and further increasing x, $\Delta d / d$ increases. This is due to down quark attains negative polarization in whole evaluated region. Figure 3 is $\Delta \bar{u} / \bar{u}$ which is the positive distribution and figure 4 is $\Delta \bar{d} / \bar{d}$ which is negative distribution. Figure 5 shows that strange quark helicity $\Delta s / s$ is negative distribution due to the dominating of down quark over than up quark distribution. According to the scaling process, the valence quarks dominate more in the higher x region than in the low x region. The polarization only occurs in the low x region and in that region more and more sea quarks and gluons are produced which is the natural consequence of this model. In the proton, up quarks distribution dominates over than the down quarks whereas for the anti quarks distribution the opposite behavior is observed.

CONCLUSION

Quark helicity distributions $\Delta u/u$, $\Delta d/d$, $\Delta\bar{u}/\bar{u}$, $\Delta\bar{d}/\bar{d}$ and $\Delta s/s$ are evaluated using thermodynamical bag model. Theoretical results are good agreement with HERMES and SMC experimental data in the kinematic region 0.02 < x < 0.6 at Q2 = 2.5 GeV2. The first and second moments of polarized valence quarks are also evaluated in measured kinematic region which are consistent with available experimental data. In conclusion, evaluation satisfies the Bjorken and momentum sum rules.

Table 1 Evaluated first and second moments are compared with HERMES and SMC experiment results at Q2 = 2.5 GeV2.

	HERMES[11]	SMC[12]	TBM
Δu_v	0.603±0.071±0.040	0.614±0.082±0.068	0.680
Δd_v	-0.172±0.068±0.045	-0.334±0.112±0.089	-0.178
$\Delta\bar{u}$	-0.002±0.036±0.023	0.015±0.034±0.024	0.120
$\Delta^{(2)}u_v$	0.144±0.013±0.011	0.152±0.016±0.013	0.141
$\Delta^{(2)}d_v$	-0.017±0.012±0.012	-0.056±0.026±0.015	-0.035

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