International Journal of Theoretical Physics, Vol. 35, No. 12, 1996

Spin Structure of the Nucleon

Katsumi Sugita,[1] Yoshiwo Okamoto,[2] and Matsuo Sekine[3]

Received December 4, 1995

Based on an infinite sublayer quark model, we determine the fraction of nucleon spin carried by subquarks.

In Sekine (1985), Sugita *et al.* (1991, 1992a,b), and Okamoto *et al.* (1992a,b) we proposed an infinite sublayer quark model according to which the proton p and the neutron n are made up of u_1 and d_1 quarks such that $p = u_1u_1d_1$ and $n = u_1d_1d_1$. Furthermore, u_1 and d_1 quarks are made up of u_2 and d_2, etc. In summary, u_N and d_N quarks at level N are made up of u_{N+1} and d_{N+1} quarks at level $N + 1$, such that $u_N = (u_{N+1}, u_{N+1}, d_{N+1})$ and $d_N = (u_{N+1}, d_{N+1}, d_{N+1})$, where $N = 1, 2, 3, \ldots, \infty$. Here, the u_N and d_N quarks have quantum numbers of spin $J = 1/2$, baryon number $B = 1/3^N$, isospin $I = 1/2$, third component of isospin $I_3 = \pm 1/2$, and fractional electric charge $Q = [(1 \pm 3^N)/(2 \times 3^N)]|e|$, where $|e|$ is the electron charge. Thus, at $N = \infty$, an infinite number of pointlike quarks (u_∞) and antiquarks ($\bar{u}_\infty = d_\infty$) is considered as constituting the nucleon. The ultimate particle u_∞ has quantum numbers of $J = 1/2$, $I = 1/2$, $I_3 = 1/2$, and $Q = 1/2 \cdot |e|$. Thus, all quantum numbers of the u_∞ quarks are just one-half and this fermion will behave as if it was a lepton, since the baryon number disappears at the infinite sublayer level.

We considered the quantum numbers of weak isospin $t_3 = 1/2$ and $t_3 = -1/2$ for the ultimate particle $u_\infty = a$ and $\bar{u}_\infty = a^{cp}$, respectively, where a^{cp} means the particle operated on by charge conjugation C and then parity

[1] Department of Electronics and Information Engineering, Sun Techno College, 1999-5, Ryuo-cho, Nakakoma-gun, Yamanashi, Japan.
[2] Department of Electrical Engineering, Chiba Institute of Technology, 2-17-1, Tsudanuma, Narashino-shi, Chiba, Japan.
[3] Department of Applied Electronics, Tokyo Institute of Technology, 4259, Nagatsuta, Midori-ku, Yokohama, Japan.

transformation P. Furthermore, we proposed a preon model in which quarks, lepton, and gauge bosons are made up of the preon $\langle\langle a\rangle\rangle$ and antipreon $\langle\langle a^{cp}\rangle\rangle$ (Sugita *et al.*, 1992a,b; 1993a,b; 1994, 1995; Okamoto *et al.*, 1994, 1995a,b). It was shown that Higgs bosons are also composed of $\langle\langle a\rangle\rangle$ and $\langle\langle a^{cp}\rangle\rangle$ (Sugita *et al.*, 1993a,b); there are just four families (Sugita *et al.*, 1993a,b) and there is a possibility of eliminating the preon self-energy divergences (Okamoto *et al.*, 1994) and CP is violated in the β-decay of the nucleon (Sugita *et al.*, 1995; Okamoto *et al.*, 1995a,b).

It has been reported that 14% of the proton spin is carried by the spin of the quarks (Ashman *et al.*, 1988), and experiments were made to explore the spin effect of the nucleon (Ashman *et al.*, 1989; Adeva *et al.*, 1993; Anthony *et al.*, 1993; Adams *et al.*, 1994). On the other hand, a soliton model having the chiral symmetry of the nucleon has been proposed to explain why little of the proton spin is carried by quarks (Brodsky *et al.*, 1988).

In the following, we shall calculate the effect of the nucleon spin by considering the infinite sublayer quark model.

Assume that the nucleon is composed of u_N and d_N quarks at sublevel N. Furthermore, we assume that there is no interaction and no binding force due to hypercolor between levels.

Then, considering the difference of the spin-dependent structure functions Δu_N and Δd_N at the Nth subquark level, we write the integral of the spin-dependent structure function $g_1^p(x)$ for the proton as

$$2\int_0^1 dx\, g_1^p(x) = Q_{u_N}^2 \Delta u_N + Q_{d_N}^2 \Delta d_N \equiv a \tag{1}$$

where

$$Q_{u_N} = \frac{1 + 3^N}{2 \times 3^N}, \qquad Q_{d_N} = \frac{1 - 3^N}{2 \times 3^N} \tag{2}$$

Also, Δu_N and Δd_N are written as

$$\Delta u_N \equiv \int_0^1 dx\, [q_{u_N}^+(x) + g_{\bar{u}_N}^+(x) - q_{u_N}^-(x) - q_{\bar{u}_N}^-(x)] \tag{3}$$

and

$$\Delta d_N \equiv \int_0^1 dx\, [q_{d_N}^+(x) + q_{\bar{d}_N}^+(x) - q_{d_N}^-(x) - q_{\bar{d}_N}^-(x)] \tag{4}$$

where the superscript + (−) means the polarized subquark is parallel (antiparallel). Furthermore, $q_{u_N}^{\pm}$ and $q_{d_N}^{\pm}$ are the distribution functions for u_N and d_N, so (3) and (4) hold regardless of the number of quarks. Similarly, the integral of the spin-dependent structure function $g_1^n(x)$ for the neutron is obtained by interchanging Δu_N and Δd_N,

$$2 \int_0^1 dx\, g_1^n(x) = Q_{d_N}^2 \Delta u_N + Q_{u_N}^2 \Delta d_N \equiv b \tag{5}$$

Substituting equation (2) into equations (1) and (5), we obtain

$$(1 + 3^N)^2 \Delta u_N + (1 - 3^N)^2 \Delta d_N = 4a \cdot 3^{2N} \tag{6}$$

and

$$(1 - 3^N)^2 \Delta u_N + (1 + 3^N)^2 \Delta d_N = 4b \cdot 3^{2N} \tag{7}$$

From equations (6) and (7), the sum of Δu_N and Δd_N is written as

$$\Delta u_N + \Delta d_N = \frac{2(a + b)3^{2N}}{1 + 3^{2N}} \tag{8}$$

At $N \to \infty$, we obtain

$$\Delta u_\infty + \Delta d_\infty = 2(a + b) \tag{9}$$

Therefore, the mean z component of the spin, S_z, of the u_∞ and d_∞ quarks is

$$\langle S \rangle_{u_\infty + d_\infty} = \frac{1}{2} (\Delta u_\infty + \Delta d_\infty) = a + b \tag{10}$$

Putting the experimental values $a = 0.272$ (Adams *et al.*, 1994) and $b = -0.138$ (Adeva *et al.*, 1994) at 5 GeV into (10), we obtain

$$\langle S_z \rangle_{u_\infty + d_\infty} = 0.134 \tag{11}$$

Hence 27% of the proton spin is carried by the spin of the u_∞ and d_∞ quarks. On the other hand, from the naive quark model, which is equivalent to our model at $N = 1$, we obtain

$$\langle S_z \rangle_{u_1 + d_1} = 0.121 \tag{12}$$

By comparing (11) with (12), we conclude that the proton spin carried by the spin of the u_∞ and d_∞ quarks is 11% larger than that carried by the spin of the u_1 and d_1 quarks. Furthermore, it is of interest to note that the experimental value including third-order QCD perturbation at the CERN Spin Muon Collaboration (SMC-p) from the simple quark model is almost the same value as 0.134 in (11) (Frois and Karliner, 1994).

REFERENCES

Adams, D., *et al.* (1994). *Physics Letters,* **329B**, 399.
Adeva, B., *et al.* (1993). *Physics Letters,* **302B**, 533.
Adeva, B., *et al.* (1994). *Physics Letters,* **320B**, 400.
Anthony, P. L., *et al.* (1993). *Physical Review Letters,* **71**, 959.
Ashman, J., *et al.* (1988). *Physics Letters,* **206B**, 364.
Ashman, J., *et al.* (1989). *Nuclear Physics,* **328B**, 1.
Brodsky, J., Ellis, J., and Karliner, M. (1988). *Physics Letters,* **206B**, 309.
Frois, B., and Karliner, M. (1994). *Physics World,* **7**, 44.
Okamoto, Y., Sugita, K., and Sekine, M. (1992a). *International Journal of Theoretical Physics,* **31**, 59.
Okamoto, Y., Sugita, K., and Sekine, M. (1992b). *International Journal of Theoretical Physics,* **31**, 2043.
Okamoto, Y., Sugita, K., and Sekine, M. (1994). *Nuovo Cimento,* **107A**, 1363.
Okamoto, Y., Sugita, K., and Sekine, M. (1995a). *Nuovo Cimento,* **108A**, 371.
Okamoto, Y., Sugita, K., and Sekine, M. (1995b). *Nuovo Cimento,* **108A**, 1153.
Sekine, M. (1985). *International Journal of Theoretical Physics,* **24**, 701.
Sugita, K., Okamoto, Y., and Sekine, M. (1991). *International Journal of Theoretical Physics,* **30**, 1079.
Sugita, K., Okamoto, Y., and Sekine, M. (1992a). *International Journal of Theoretical Physics,* **31**, 521.
Sugita, K., Okamoto, Y., and Sekine, M. (1992b). *Nuovo Cimento,* **105A**, 1051.
Sugita, K., Okamoto, Y., and Sekine, M. (1993a). *Nuovo Cimento,* **106A**, 271.
Sugita, K., Okamoto, Y., and Sekine, M. (1993b). *Nuovo Cimento,* **106A**, 771.
Sugita, K., Okamoto, Y., and Sekine, M. (1994). *Nuovo Cimento,* **107A**, 1793.
Sugita, K., Okamoto, Y., and Sekine, M. (1995). *Nuovo Cimento,* **107A**, 2875.