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Resonance region spin structure functions for proton and deuteron

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The proton and deuteron spin structure functions g_1^p and g_1^d are evaluated in the resonance region of $W^2 < 5$ GeV^2 at $Q^2 = 0.5$ and 1.2 GeV^2 by thermodynamical Bag model (TBM). The calculated values are compared with the measured values obtained by the deep inelastic scattering (DIS) of 9.7 GeV polarised electrons off polarised $^{15}NH_3$ and $^{15}ND_3$ targets.

1 Introduction

Even though the nucleon spin structure functions g_1 and g_2 are under intensive investigation[1-6] through deep inelastic scattering (DIS) it is still incomplete in the resonance region by a large extent, where the square of the invariant mass W^2 of the final hadronic state is less than 4 GeV^2. In this region the helicity structure of the resonance transition amplitudes can be investigated through g_1 and g_2. The measured values of $A_1(x, Q^2)$ in the resonance region are due to the combination of asymmetries $A_1(x, Q^2)$ and $A_2(x, Q^2)$ for individual resonances in the non- resonant background. The measurement of the spin dependent structure functions of proton and deuteron in the resonance region[7] yields a better understanding of spin projections of resonances g_1^p, g_1^n in the negative region and enables us to find the impact on DIS results both in the cases of radiative corrections and the evolution of $r(Q^2) = \int g_1(x, Q^2)dx$. The resonant contribution to r is significant at a low Q^2 region, and it remains unperturbed above this value. Gerasimov-Drell-Hearn (GDH) sum rule indicates that $r(Q^2)$ should change sign in the region $0 < Q^2 < 1$ GeV^2 and must tend to zero as Q^2 becomes zero. Experimental data on g_1^p and g_1^d were obtained for longitudinal target polarization only. Additional analysis is required for g_2 and A_2 for the precise determination of g_1 and A_1. g_1 is more preferred rather than A_1 since g_1 is less affected by the insufficient details available about g_2 or A_2. In the experimental analysis A_2 is made equal to zero for $g_1 = -g_2$ under the guidance $|A_2| < \sqrt{R}$, where $R \equiv \sigma_L / \sigma_T$. The available[8] experimental data point out that R is very low in the resonance region ($R = 0.06 \pm 0.02$) for $1 < Q^2 < 8$ GeV^2 and $W^2 < 3$ GeV^2. The sensitivity to A_2 is also investigated in this analysis by considering the alternate possibilities, $g_2 = 0$ and the Wandzura-Wilczek condition[9]:

$$g_2^{WW} = -g_1 + \int_x^1 g_1(x')/(x')\, dx' \quad ...(1)$$

Experimental data on g_1 is derived from the absolute cross- section deviations for electron and nucleon spins either parallel or antiparallel to each other along the beam axis. The experimental values of g_1 are extracted from the count rate asymmetry. In the resonance region the required dilution factor, the fraction of scatterings coming from a polarizable nucleon in the target cannot be obtained precisely. In this article the spin dependent structure functions g_1^p and g_1^n of proton and neutron and their integral values r_1^p and r_1^n are evaluated in the resonance region using thermodynamical Bag model and the results are compared with the latest experimental data[7].

2 Thermodynamical Bag Model

In this model[10-14] the Fermi and Bose distributions are utilised to derive the quark and gluon distributions in the infinite momentum frame(IMF). Here the quarks and gluons are treated as fermions and bosons, respectively confined in a volume V at temperature T. The invariant mass W of the excited nucleon is identified with that of the final hadronic system. This is derived from the hypothesis that the energy transfer to the nucleon causes heating up of the constituent quark gluon system and expressed as:

$$W = [\varepsilon_u(T) + \varepsilon_d(T) + \varepsilon_g(T)]\,V \qquad ...(2)$$

where ε_u, ε_d and ε_g are the energy densities of u and d quarks and gluons at a temperature T. The square of the invariant mass is given by:

$$W^2 = M^2 + 2M\nu - Q^2 \qquad ...(3)$$

Solving Eqs (2) and (3) simultaneously by fixing Q^2 (0.5 and 1.2 GeV^2), the chemical potentials μ_u and μ_d of u and d quarks are evaluated, which satisfy the number of valence quarks in proton and neutron, respectively. The decrease in the value of the Bjorken variable x yields the increase of invariant mass of the final hadronic system and this leads to the enormous production of sea quarks and gluons.

The rise in the temperature results in the corresponding increase in the volume of the bag and decrease in the chemical potentials, from which the quark and spin distribution functions are evaluated.

3 Evaluation of g_1^p and g_1^d in the Resonance Region Through TBM

Let $\Delta q(x)$ denote the difference between the probability of finding a quark or antiquark of positive helicity and momentum fraction x and the corresponding probability of finding a quark or antiquark with negative helicity. Then

$$\Delta q(x) = [q^{\uparrow}(x) + \bar{q}^{\uparrow}(x) - q^{\downarrow}(x) - \bar{q}^{\downarrow}(x)] \qquad ...(4)$$

The valence quark spin distribution functions are evaluated after modulating the quark distributions by the spin dilution factor. The spin dilution factor is used in such a manner that this model may fulfil the Bjorken sum rule.

The spin dependent structure functions for proton $g_1^p(x)$ and neutron $g_1^n(x)$ are expressed as :

$$g_1^p(x) = 0.5[(4/9)\Delta u_v(x) + (1/9)\,\Delta d_v(x)] \qquad ...(5)$$

$$g_1^n(x) = 0.5[(1/9)\Delta u_v(x) + (4/9)\,\Delta d_v(x)] \qquad ...(6)$$

$$g_1^d(x) = 0.5\,(g_1^p(x) + g_1^n(x)) \qquad ...(7)$$

where $\Delta u_v(x)$ and $\Delta d_v(x)$ are the spin distribution functions of the valence quarks u and d, respectively.

The radius of the nucleon R, the temperature of the system T and the chemical potentials μ_u and μ_d are obtained for the required value of Q^2 (0.5 and 1.2 GeV^2) by solving self-consistently the four equations of state of the thermodynamical Bag model. These are used to determine the values of $g_1^p(x)$, $g_1^n(x)$ and $g_1^d(x)$. The calculated values are plotted, compared with the measured values and shown in Figs 1 and 2.

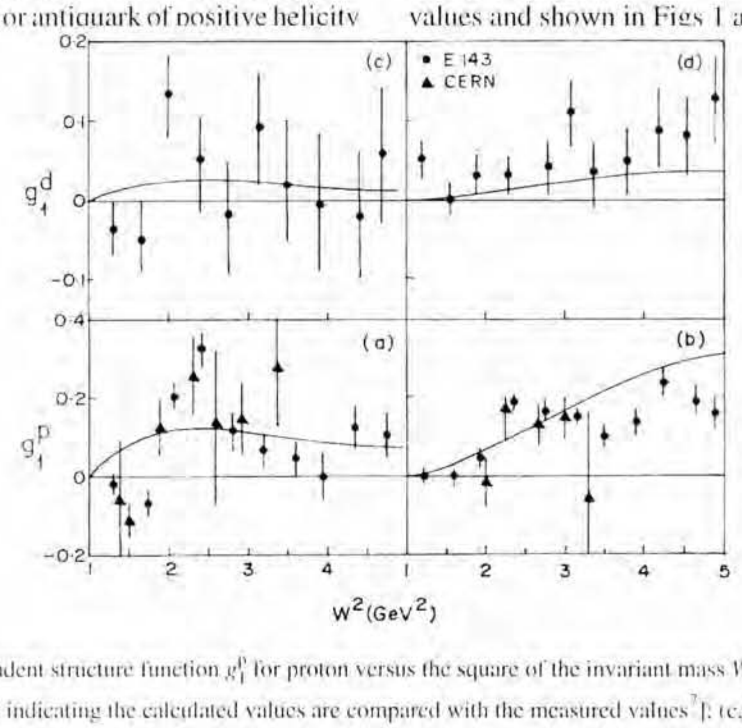

Fig. 1 — (a,b) The spin dependent structure function g_1^p for proton versus the square of the invariant mass W^2 for 0.5 and 1.2 GeV^2, respectively [the solid curves indicating the calculated values are compared with the measured values[7]]; (c,d) The spin dependent structure function g_1^d for deuteron versus the square of the invariant mass W^2 for 0.5 and 1.2 GeV^2, respectively [the solid curves indicating the calculated values are compared with the measured values[7]]

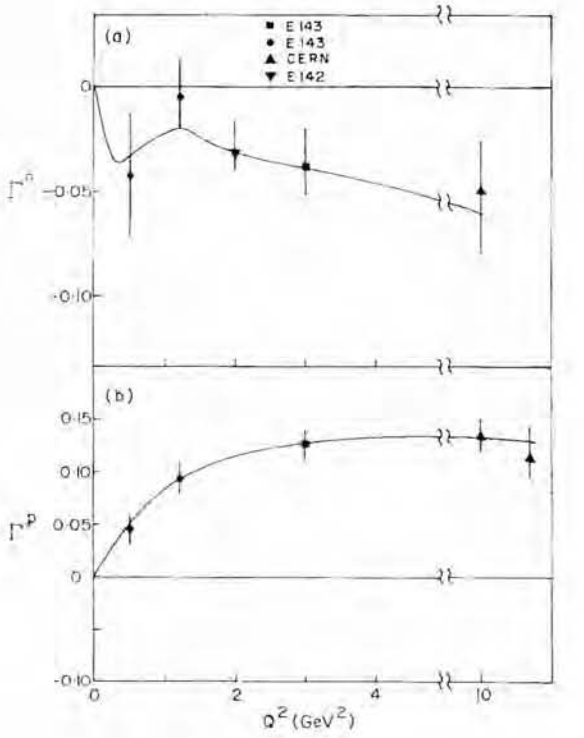

Fig. 2 — (a,b) The integral values of spin dependent structure functions for neutron Γ_1^n and proton Γ_1^p as a function of the square of the four momentum transfer Q^2 are compared with the experimental data[7]

4 Results and Discussions

In this model the temperature, the chemical potentials and the radius of the bag are derived for the quarks after identifying the final hadronic state invariant mass obtained through DIS with the energy of the excited thermodynamical nucleon. The Fermi distribution function is transformed to the IMF, to get the quark distribution functions and by using the above bag variables the nucleon structure functions g_1^p, g_1^n and their integral values Γ_1^p and Γ_1^n are calculated in the resonance regions corresponding to $Q^2 = 0.5$ and 1.2 GeV^2, respectively and compared with the available measured values. This confirms the dominance of the sea quarks and gluons in the low Q^2 region for the spin dependent structure functions of both proton and neutron.

The integral value of the spin dependent structure function for proton Γ_1^p varies very rapidly in the low Q^2 region ($Q^2 < 2$ GeV^2) compared to the nearly flat behaviour in the high Q^2 regions, where as the integral value of the same function for neutron Γ_1^n shows a negative peak in the resonance region and falls off rapidly for higher values of Q^2 after a slight increase in this region. This feature again indicates the predominance of sea quarks and gluons in the resonance region for neutron as well. It is found that a part of the proton spin is carried away by the valence quarks. The spin carried away by the sea quarks is considerable and it is polarised in a direction opposite to that of proton. It is seen that the GDH sum rule is strictly applicable only at $Q^2 = 0$, where $\Gamma(Q^2)$ becomes zero. This can be utilised to predict the slope of $\Gamma(Q^2)$ for small Q^2.

5 Conclusions

The behaviour of spin dependent structure functions g_1^p and g_1^n of proton and neutron and their integral values Γ_1^p and Γ_1^n has been studied in the resonance region ($Q^2 <$ 2 GeV^2) using thermodynamical Bag model and the calculated values are compared with the measured data[7] of E142, E143 and CERN. The agreement between the two is found to be fairly good.

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