Nuclear medium effects in electromagnetic and weak structure functions at moderate Q^2

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Introduction

In the deep inelastic scattering(DIS) region, a better theoretical understanding of the nuclear medium effects(NME) has been recently emphasized both for the electromagnetic and weak interactions induced processes. This is in view of the present DIS experiments being performed on various nuclear targets using the electron beam at the JLab and the (anti)neutrino beam at the Fermilab. The goals of these experiments is to study the NME in the wide range of x and Q^2. On the theoretical side, there are few models which have been developed to understand the NME in the weak interaction induced processes. In this thesis, we have theoretically studied NME both in the electromagnetic and weak interactions induced processes in the wide range of x and Q^2 [1, 2] for the different nuclear targets like ^{12}C, ^{27}Al, ^{56}Fe, ^{63}Cu, ^{208}Pb, etc.

Formalism

We have studied the NME in the nuclear structure functions(nSF) using a microscopic approach based on the field theoretical formalism. We incorporate the NME arising due to the Fermi motion, binding energy and nucleon correlations through the spectral function [3] which is obtained by using the Lehmann's representation for the relativistic nucleon propagator and many body theory has been used to calculate it for an interacting Fermi sea in the nuclear matter. Then to evaluate the results for the finite nuclei, we apply the local density approximation. Furthermore, the effects due to the mesonic contribution and shadowing are also taken into account by following Refs. [3] and [4], respectively. For the numerical calculations, we have used the CTEQ6.6 parton distribution functions(PDFs) for the nucleon and the parameterization given by Gluck et al. for the pion as well as for the rho meson [5]. Furthermore, different parameterizations for the nucleon, pion and the nuclear PDFs has also been studied. The numerical results are evaluated at leading order(LO) as well as next-to-the leading order(NLO) with target mass correction(TMC) effect. In the present model, we have obtained the following expressions for the dimensionless nSF [1, 2]:

$$F_{1A}^{EM(WI)}(x_A, Q^2) = 4AM_N \int d^3r \int \frac{d^3p}{(2\pi)^3} \frac{M_N}{E(\vec{p})} \int_{-\infty}^{\mu} dp_0 S_h(p_0, \vec{p}, \rho(\vec{r})) \left[\frac{F_{1N}^{EM(WI)}(x_N, Q^2)}{M_N} + \frac{{p_x}^2}{M_N^2} \frac{F_{2N}^{EM(WI)}(x_N, Q^2)}{\nu} \right],$$

$$F_{2A}^{EM(WI)}(x_A, Q^2) = 4 \int d^3r \int \frac{d^3p}{(2\pi)^3} \frac{M_N}{E(\vec{p})} \times \int_{-\infty}^{\mu} dp_0 S_h(p_0, \vec{p}, \rho(\vec{r})) \times \left[\frac{Q^2}{q_z^2} \left(\frac{|\vec{p}|^2 - p_z^2}{2M_N^2} \right) + \frac{(p_0 - p_z \gamma)^2}{M_N^2} \left(\frac{p_z Q^2}{(p_0 - p_z \gamma) q_0 q_z} + 1 \right)^2 \right] \frac{M_N}{p_0 - p_z \gamma} F_{2N}^{EM(WI)}(x_N, Q^2),$$

where M_N is the mass of the nucleon, $\gamma = \frac{q^z}{q^0}$, p_z is the momentum of nucleon along the z-axis and S_h is the hole spectral function. Bjorken variable, $x_A = \frac{Q^2}{2\ M_A\ q_0}$ corresponds to the nuclear target which is at rest and $x_N = \frac{Q^2}{2(p_0 q_0 - p_z q_z)}$ to the nucleons that are moving inside the nucleus. Similar, expressions are obtained for the pion and rho meson

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structure functions by replacing S_h with the mesonic propagator [1, 2].

We have also studied the NME in the ratio of longitudinal to transverse structure functions $R_{L,A}^{EM(WI)}(x,Q^2) = \frac{F_{L,A}^{EM(WI)}(x,Q^2)}{2xF_{1A}^{EM(WI)}(x,Q^2)}$, where the longitudinal structure function $F_{L,A}^{EM(WI)}(x,Q^2)$ is given by

$$F_{L,A}^{EM(WI)}(x,Q^2) = \left(1+\frac{4M_N x^2}{Q^2}\right) F_{2A}^{EM(WI)}(x,Q^2) - 2xF_{1A}^{EM(WI)}(x,Q^2).$$

Furthermore, we have studied the behaviour of the Callan-Gross relation(CGR), i.e. $2xF_{1N}(x,Q^2) = F_{2N}(x,Q^2)$, in the nuclear medium for which we obtain the results for $\frac{2xF_{1A}^{EM(WI)}(x,Q^2)}{F_{2A}^{EM(WI)}(x,Q^2)}$ and $2xF_{1A}^{EM(WI)}(x,Q^2) - F_{2A}^{EM(WI)}(x,Q^2)$. The numerical results are obtained for the three different cases: **(i)** with spectral function(SF) only, **(ii)** including meson contribution with SF(SF+$\pi+\rho$) and **(iii)** further including the shadowing effect with **(ii)**, i.e. our full model(Total).

Results and Discussion

By using the present formalism, first we have obtained the results for the free nucleon structure function $F_{2N}^{EM}(x,Q^2)$ vs x at LO and NLO for $Q^2 = 2$ GeV^2 and found that there is a difference of 20% at $x = 0.1$, 3% at $x = 0.3$ and 57% at $x = 0.6$, respectively. We also performed the calculations at NNLO and found that these results differ within a percent from the results at NLO. The results for $F_{2N}^{EM}(x,Q^2)$ with the TMC effect are also obtained and we observe that TMC effect is important in the region of high x and low Q^2. Then we have evaluated the electromagnetic nSF $F_{2A}^{EM}(x,Q^2)$ with the spectral function only in a wide range of x and Q^2 for the various nuclear targets. For example using SF in carbon, at $Q^2 = 2$ GeV^2 there is a difference of $\sim 6\%$ at $x = 0.1$, 17% at $x = 0.5$, and 7% at $x = 0.7$, respectively, from the free nucleon case. We find that the inclusion of mesonic contribution which is significant at low and intermediate x cause an enhancement in this difference, i.e. $\sim 28\%$ at $x = 0.1$, 11% at $x = 0.5$, however, for the higher values of x it becomes negligible. When we further include the shadowing effect, a reduction($\approx 5-7\%$) is obtained in the region of low $x(< 0.1)$. NME are found to be more pronounced with the increase in the mass number, however, become small with the increase in Q^2. We have also obtained the results for the nSF $2xF_{1A}^{EM}(x,Q^2)$ and find them qualitatively similar to the results of $F_{2A}^{EM}(x,Q^2)$ but quantitatively different specially for low x. The numerical results have been compared with the recent experimental data of the JLab as well as with the data of EMC, BCDMS and NMC experiments. Furthermore, we observe that CGR deviates in the nuclear medium for the region of high x and low Q^2. We have also performed the calculations in the case of weak interaction and compared the results with the electromagnetic nSF. The behaviour of the weak structure functions are found to be similar as the electromagnetic structure functions but they are quantitatively different in the region of low $x(\leq 0.3)$. Hence we conclude that NME are different for the electromagnetic and weak structure functions which were phenomenologically taken to be the same. The results for the weak interaction show a fair agreement with the available experimental data of NuTeV, CCFR, CDHSW and CHORUS. This study would be helpful in the analysis of JLab and MINERνA experiments.

References

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