RESPONSE FUNCTIONS AND DIFFERENTIAL CROSS SECTIONS FOR NEUTRINO SCATTERING OFF ^{2}H*

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The need of a better understanding of the weak interaction and the electro-weak unification triggered in the last decades an interest in neutrino scattering off nuclei. Here, we present a study on neutrino-induced reactions off ^{2}H. The cross sections are calculated via the nuclear response functions, which contain the information about the nuclear structure and interactions.

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1. Introduction

Not only nuclear physics but also other fields of physics such as astrophysics and particle physics have interest in a better understanding of neutrino reactions on nuclei. The knowledge about this type of reactions is also a requirement for the construction of neutrino detectors [1, 2]. At least for the lightest nucleus, ^{2}H, equivalent results arise from calculations performed in both coordinate and momentum space. This leads to the conclusion that

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the theoretical uncertainty may be small at low energies [3, 4]. These studies were carried out by adopting semi-phenomenological potentials as well as ones based on the chiral effective field theory [5], and the related single- and two-nucleon current operators. We tested successfully our momentum-space framework in the reactions on the deuteron, obtaining a very good agreement with the calculations presented in Ref. [3], especially in the low-energy regime, where the two-nucleon contribution in the weak current operator do not play any important role. This constitutes for us a promising starting point for calculations planned in the three-nucleon system.

In this study, we make use of the semi-phenomenological potential AV18 [6] and the single-nucleon current.

2. The differential cross section

In this contribution, we restrict ourselves to the following neutrino induced reactions: $\bar{\nu}_e + {}^2\text{H} \rightarrow e^+ + n + n$, $\nu_e + {}^2\text{H} \rightarrow e^- + p + p$, $\bar{\nu}_e + {}^2\text{H} \rightarrow \bar{\nu}_e + p + n$ and $\nu_e + {}^2\text{H} \rightarrow \nu_e + p + n$.

By defining the inclusive response functions R^{inc}_{AB} as [4]

$$R^{\text{inc}}_{AB} = \sum_{m_\text{i}\, m_\text{f}} \int \text{d}f\, \delta\left(E_\text{CM} - E_\text{f}\right) \langle \Psi_\text{f} | \, j^A \, | \Psi_\text{i} \rangle \langle \Psi_\text{i} | \, j^B \, | \Psi_\text{f} \rangle \,, \tag{1}$$

we can express the differential cross section for the above-mentioned reactions as [4]

$$\frac{\text{d}^3\sigma}{\text{d}E'\,\text{d}\Omega'} = \frac{G_\text{F}^2 \cos^2\theta_\text{C}}{(2\pi)^2} F(Z,E') \frac{k'}{8E} \times \left(V_{00}R_{00} + V_{PP}R_{PP} + V_{MM}R_{MM} + V_{ZZ}R_{ZZ} + V_{Z0}R_{Z0}\right) , \tag{2}$$

where G_F is the Fermi constant, θ_C is the Cabibbo angle, k' (E') is the final lepton momentum magnitude (energy), E is the initial lepton energy, Z is the final charge of the hadronic state and $F(Z,E')$ is the Fermi function, which takes into account the Coulomb distortion of the final electron-wave function. For neutral current reactions, $\cos\theta_\text{C}$ and $F(Z,E')$ are substituted by 1.

In order to evaluate the differential cross section in Eq. (2), it is necessary to calculate the response functions in Eq. (1).

Having these functions and the differential cross section, it is possible to calculate the total cross section at a given energy, given by

$$\sigma(E)_\text{tot} = \int_0^\pi \text{d}\theta' \sin\theta' \int_0^{2\pi} \text{d}\phi' \int \text{d}E' \, \frac{\text{d}^2\sigma}{\text{d}E'\text{d}\Omega'} \,. \tag{3}$$

The results for the total cross section of the four considered reactions are shown in Fig. 1. We tested the response function method by comparing the results obtained for the deuteron break-up reactions with direct calculations, finding less than one percent deviations between the two methods.

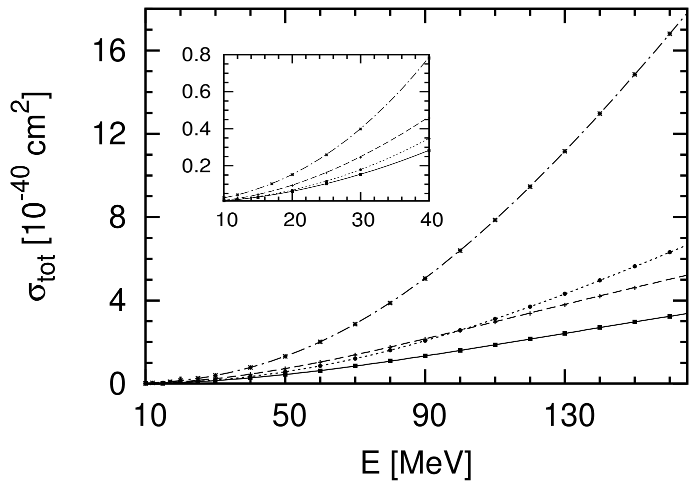

Fig. 1. The total cross section $\sigma_{\rm tot}(E)$ defined in Eq. (3) for the $\bar{\nu}_e + {}^2{\rm H} \rightarrow e^+ + n + n$ (dashed line), $\nu_e + {}^2{\rm H} \rightarrow e^- + p + p$ (dash-dotted line), $\bar{\nu}_e + {}^2{\rm H} \rightarrow \bar{\nu}_e + p + n$ (solid line) and $\nu_e + {}^2{\rm H} \rightarrow \nu_e + p + n$ (dotted line) reactions as a function of the initial (anti)neutrino energy E calculated directly (symbols) or from the interpolated response functions (lines) as explained in the text. The results are obtained with the AV18 potential and with the single-nucleon current, employing the nonrelativistic kinematics. The inset focuses on the results for $E \leq 40$ MeV. This figure was taken from Ref. [7].

3. Conclusions

We performed a study of the differential and total cross sections for several (anti)neutrino break-up reactions with ^{2}H. The method used is called the response function method and has been tested with the direct method to check the convergence of the results. It has been also applied in the three-nucleon system [7]. This study has been performed by using the simple single-nucleon current operator and can be improved by adding many-nucleon currents.

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