In-medium Effects on Neutrino Reactions inside the Neutron Star

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The nucleon form factors in free space are usually thought to be modified when a nucleon is bound in a nucleus or immersed in a nuclear medium. We investigated effects of the density-dependent axial and weak vector form factors on the electro-neutrino (ν_e) and antielectro-neutrino ($\bar{\nu}_e$) reactions with incident energy $E_\nu \leq 80$ MeV via neutral current (NC) and charged current (CC) for a nucleon in a nuclear medium or ^{12}C. For the density-dependent form factors, we exploited the quark meson-coupling (QMC) model.

In CC reaction, about 5 % decrease of the ν_e reaction cross section on the nucleon is shown to be occurred in normal density, $\rho = \rho_o \sim 0.15\, fm^{-3}$ (see Fig. 1 (left)), and also about 5 % reduction of total ν_e cross section on ^{12}C is obtained by the modification of the weak form factors for bound nucleons (Fig. 2 (left)). Density effects for both cases are relatively small, but they are as large as the effect by the Coulomb distortion of outgoing leptons in the ν-reaction. However, density effects in the $\bar{\nu}_e$ reaction reduced significantly about 30 % the cross sections for both the nucleon and ^{12}C cases [1].

For NC, about 12 % decrease of the total cross section by the ν_e reaction on the nucleon is obtained at normal density, $\rho = \rho_o \sim 0.15\, fm^{-3}$ (Fig. 1 (right)), as well as about 18 % reduction of the total ν_e cross section on ^{12}C (Fig. 2 (right)), by the modification of the weak form factors of the bound nucleon.

However, similarly to the CC reaction, effects of the nucleon property change in the $\bar{\nu}_e$ reaction and reduce significantly the cross sections about 30 % for the nucleon in matter and ^{12}C cases. In Refs. [1,2], we addressed that such a large asymmetry in the $\bar{\nu}_e$ cross sections in both reactions is originated from the different helicities of $\bar{\nu}_e$ and ν_e.

We have applied the QRPA formalism to ^{12}C(ν_e, e^-)^{12}N$_{g.s.}$(1$^+$) via CC and ^{12}C(ν_e, ν'_e)^{12}C*(1$^+$) via NC. The reaction can be treated by the $\Delta J = 1$ transition from the 0$^+$ ground state of ^{12}C to the 1$^+$ ground state of ^{12}N and ^{12}B. Descriptions of the nuclear states are performed by the QRPA framework [3]. Recent neutrino facilities present lots of fruitful data for the neutrino reaction in the quasi-elastic region. The study of the asymmetry between the $\bar{\nu}$ and ν scattering by more data could be the valuable alternative approach to understand the modification of the nucleon properties in a nuclear medium.

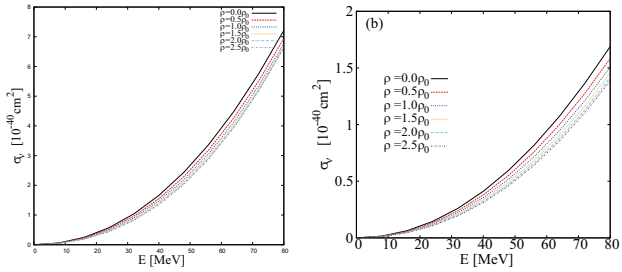

Figure 1: Density dependence of total cross sections for $\nu_e + n \rightarrow e^- + p$ (left) and $\nu_e + n \rightarrow \nu'_e + n$ (right) reactions in nuclear matter. Cross sections are decreased with the increase of the density by $\rho/\rho_o = 0$ (black (solid)) $\rho/\rho_o = 0.5$ (red (dashed)), 1.0 (blue (dotted)), 2.0 (yellow (short dotted)) and 2.5 (sky-blue (dot-dashed)) in both reactions.

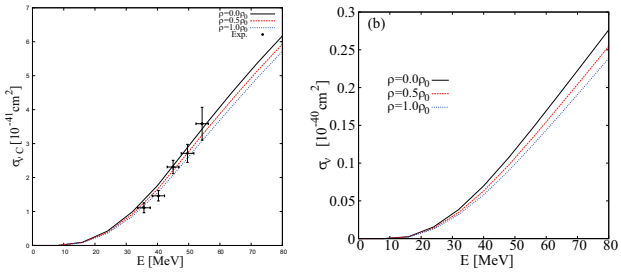

Figure 2: Density dependence in ^{12}C(ν_e, e^-)^{12}N$_{g.s.}$(1$^+$) (left) and ^{12}C(ν_e, ν'_e)^{12}C*(1$^+$) (right) reactions. Uppermost (black (solid)) curve ($\rho = 0$) in right panel is the same result as the results by the 1$^+$ transition as the Fig. 1 in Ref. [3], which neatly reproduced the energy-dependent cross section data [4]. Cross sections are decreased similarly to the nucleon case in Fig. 1.

References

[1] Cheoun, M.-K., et al.: 2013, *Phys. Lett. B*, **723**, 464.
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[3] Cheoun, M.-K., et al.: 2010, *Phys. Rev. C*, **81**, 028501.
[4] Athanassopoulos, C., et al.: 1997, *Phys. Rev. C*, **55**, 2078.