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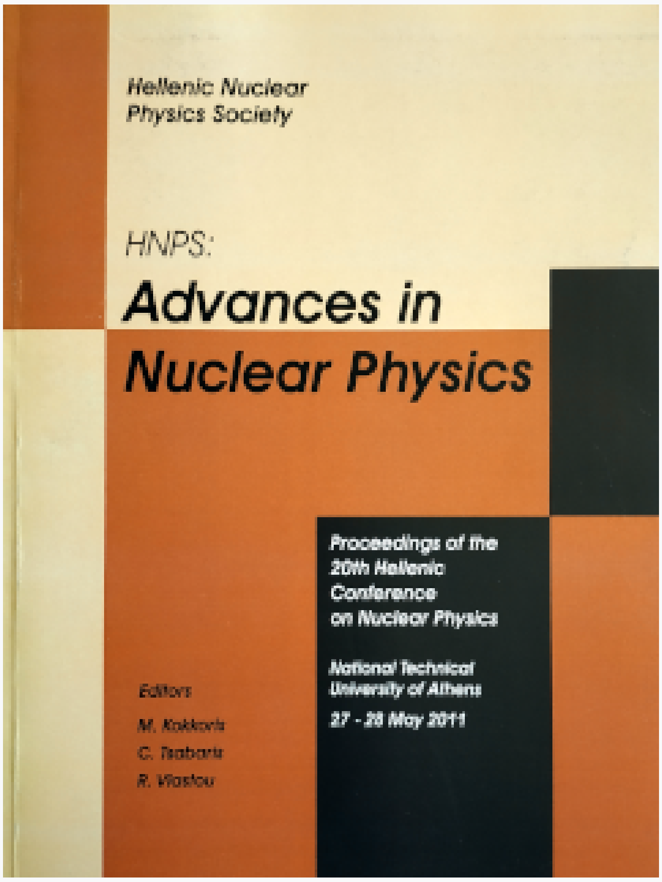

Neutrino scattering off the 95,97Mo isotopes

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Neutrino scattering off the ^{95,97}Mo isotopes

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Abstract

In this work we perform calculations of the cross sections for neutral-current neutrino scattering off the ^{95,97}Mo isotopes. Both the incoherent and coherent contributions to the cross sections are considered. The wave functions of the initial and final nuclear states are constructed in the context of the quasiparticle phonon model (MQPM). The response of the aformentioned nuclei to supernova neutrinos are computed by folding the obtained cross sections with a two-parameter Fermi-Dirac distribution.

Key words: Semi-leptonic electroweak interactions, neutrino-nucleus reactions, inelastic cross sections, quasi-particle random phase approximation
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1 Introduction

The fact that neutrinos are becoming very crucial in nuclear and astroparticle physics depends on their ability of reaching terrestrial matter when other traditional messengers fail. For this reason probing solar properties with neutrinos provides a powerful modality for stellar investigation, ranging from nucleosynthesis [1], [2], [3], [4], [5] to supernova detection [6], [7]. Obviously, terrestrial experiments to detect these neutrinos are incredible sources of astrophysical information and observational neutrino astrophysics is an extremely rapidly expanding research field [8], [9].

Various theoretical models have been developed to support the current neutrino experiments. For the results that are performed in the following description neutral current reactions have been considered [10]. Recently, neutrino-nucleus cross section calculations at low and intermediate neutrino-energies have been employed for studying the nuclear response to astrophysical neutrino spectra [11]. In the present work, we devote a special effort on this topic by performing realistic calculations for the dependence on the scattering angle and initial neutrino-energy of the differential and integrated cross sections of the reactions $^{95}Mo(\nu,\nu')^{95}Mo^{*}$ and $^{97}Mo(\nu,\nu')^{97}Mo^{*}$.

2 The Microscopic Quasiparticle Phonon Model (MQPM)

In this work the MQPM (microscopic quasiparticle-phonon model) is adopted to construct the nuclear states of the ^{95,97}Mo isotopes [12]. In the MQPM the states of an odd-A nucleus are formed by coupling together BCS quasiparticles and QRPA (quasiparticle randm-phase approximation) phonons. The first step is to create the quasiparticle states in a BCS calculation. The quasiparticles are defined by the Bogolyubov-Valatin transformation as :

$$a_{\alpha}^{\dagger} = u_a c_{\alpha}^{\dagger} + v_a \tilde{c}_{\alpha}, \tag{1}$$

$$\tilde{a}_{\alpha} = u_a \tilde{c}_{\alpha} - v_a c_{\alpha}^{\dagger}, \tag{2}$$

where the index α contains the single-particle quantum numbers n_α, l_α and j_α and the index α includes furthermore the magnetic quantum number m_α. Here, $c_{\alpha}^{\dagger}$ is the particle creation operator and the time-reversed particle annihilation operator $\tilde{c}_{\alpha}$ is defined by $\tilde{c}_{\alpha} = (-1)^{j_a+m_\alpha} c_{-\alpha}$ with $-\alpha = (a, -m_\alpha)$. The QRPA states of the even-even reference nucleus are subsequently formed by coupling two-quasiparticle operators to well-defined angular momenta J_ω and parities π_ω. In the final step of the MQPM calculation the three-quasiparticle states of the odd-A nucleus are constructed by coupling together the quasiparticles and QRPA phonons. The creation operator for the ith MQPM state of angular momentum j is therefore given by

$$\Gamma_i^{\dagger}(jm) = \sum_n C_n^i a_{njm}^{\dagger} + \sum_{a,\omega} D_{a\omega}^i [a_a^{\dagger} Q_{\omega}^{\dagger}]_{j,m}, \tag{3}$$

where the first term is the one-quasiparticle contribution and the amplitudes C_n^i and $D_{a\omega}^i$ are computed from the MQPM equations of motion.

3 Results and Discussion

In this work we have performed realistic state-by-state calculations for inelastic and elastic neutrino-nucleus scattering off the ^{95,96}Mo isotopes. First the single-particle energies were computed from the Coulomb-corrected Woods-Saxon potential using the Bohr-Mottelson parametrization [**?**]. In the calculations a valence space containing the $3\hbar\omega$ and the $4\hbar\omega$ harmonic oscillator shells plus the $0h_{11/2}$ was used for both protons and neutrons. The particle-particle strength (g_{pp}) and the particle-hole strength (g_{ph}) were adjusted for each multipole in order to reproduce the low-lying experimental energy spectrum of the even-even nucleus under consideration [13], [14], [15], [20], [21]. In the final step the MQPM calculations were performed with no additional adjustments of parameters.

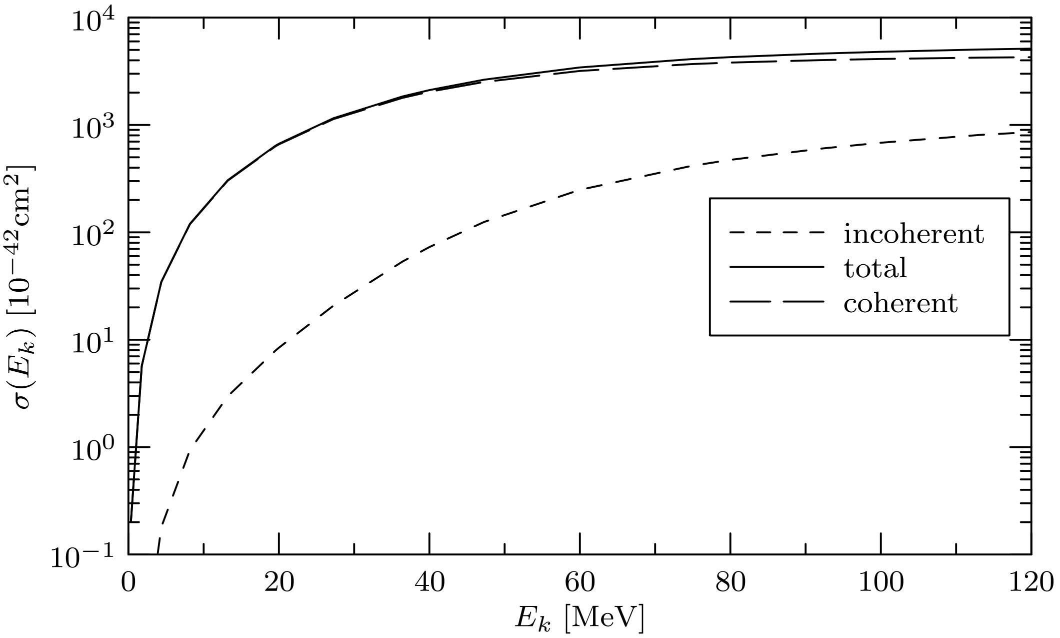

Fig. 1. The total cross section and its coherent and incoherent contributions for the neutral-current neutrino-nucleus scattering off ^{95}Mo as functions of the energy E_κ of the incoming neutrino.

In the next step we calculated the double-differential cross sections. All QRPA states with $J_\omega \leq 10$ ($\pi_\omega = -, +$) and $E_\omega \leq 40$ MeV were included. The angular integrals were performed with 10-point Lagrange-Gauss quadrature and the scattering angles are therefore given by the ten abscissas (after a change of the integration interval). The integrals over neutrino energy were similarly evaluated by using 15-point Laguerre-Gauss quadrature to integrate over the temperature-scaled variable $x = \epsilon_i/T$. In order to visualize the results we also calculated for the scattering angles $\theta = 0°, 30°, 60°, \ldots, 180°$ and the neutrino energies $E_\nu = 10, 20, 30, \ldots, 100$ MeV.

The total cross sections as functions of incoming neutrino energy (E_ν) were then obtained from the double-differential cross sections by summing over all discrete final states and subsequently integrating over all scattering angles. There is a quite wide literature describing coherent neutrino scattering experiments [16] but only one reaction of this kind has been experimentally observed

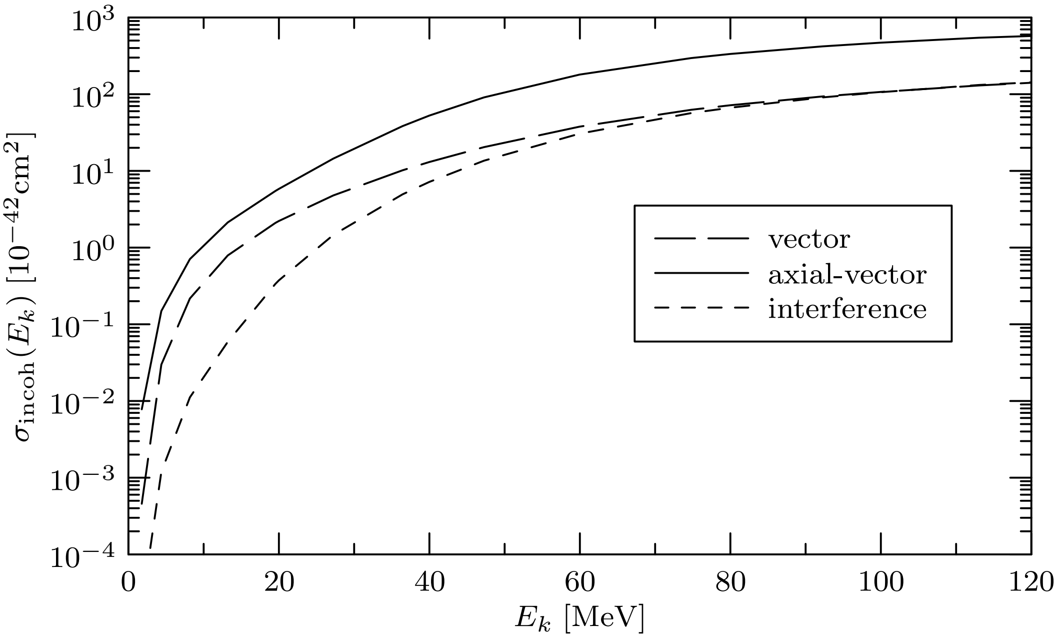

Fig. 2. Vector, axial-vector and interference contributions to the incoherent cross section for the neutrino-nucleus reaction ^{95}Mo$(\nu, \nu')^{95}$Mo* as functions of the energy E_κ of the incoming neutrino.

(see e.g. [17]). In Fig. 1 we therefore show the coherent and incoherent contributions to the neutrino scattering off ^{95}Mo as functions of the energy of the incoming neutrino. As is seen in the figure the coherent channel dominates the cross section for neutrino energies $E_\kappa \preceq 80MeV$ which are important for supernova neutrinos.

The neutrino-nucleus cross sections contain contributions from transitions of both axial-vector and vector nature. In Fig. 2 we present the purely vector, the purely axial-vector and the interference contributions to the cross section for the incoherent neutrino scattering off ^{95}Mo as functions of the neutrino energy E_κ. It is visible from the figure that transitions of axial vector character are the most prominent. The contribution from the vector type of transitions is also important especially in the low energy region, i.e. $E_\kappa \leq 40MeV$. At small neutrino energies the interference contribution is small meaning that the nucleus responds roughly in the same way to neutrinos and antineutrinos. Contrary to the incoherent channels the $g.s. \longrightarrow g.s.$ transition, which constitues the coherent channel, is of almost purely vector character.

The interesting quantity from an experimental point of view is the so called averaged cross section, $\langle\sigma\rangle$, which is obtained by folding the total cross section $\sigma(E_\nu)$ with the corresponding spectrum of neutrino energies. A pinched Fermi-Dirac distribution [18] characterized by the neutrino temperature T and the parameter α was used and the averaged cross sections for all the nuclei under consideration were evaluated. The corresponding neutrino temperatures were

flavour	α	T	$\langle E_\kappa \rangle$	$\langle \sigma \rangle^{A=95}_{incoh}$	$\langle \sigma \rangle^{A=95}_{coh}$	$\langle \sigma \rangle^{A=97}_{incoh}$	$\langle \sigma \rangle^{A=97}_{coh}$
ν_e	2.1	3.6	13.0	4.60	349	4.80	356
$\bar{\nu}_e$	3.2	3.8	15.4	6.03	463	6.26	472
ν_μ, ν_τ	0.8	4.8	15.7	8.58	494	8.80	504
$\bar{\nu}_\mu, \bar{\nu}_\tau$	0.8	4.8	15.7	7.40	494	7.59	503

Table 1
Averaged coherent and incoherent cross sections for ^{95}Mo and ^{97}Mo in units of $10^{-42} cm^2$ for the different neutrino flavours. The adopted values of α and T are those of [**?**].

calculated from the average neutrino energies ($\langle E_\nu \rangle$) of [19] and that

$$\langle E_\nu \rangle \approx \begin{cases} 3.15T & \text{for } \alpha = 0.0, \\ 3.99T & \text{for } \alpha = 3.0. \end{cases} \tag{4}$$

In Table 1 we list the computed coherent and incoherent cross sections for the aforementioned targets for all neutrino flavours. We can conclude that the results are similar for the two isotopes. Both the coherent and the incoherent cross sections increase rapidly with increasing mean energy $\langle E_\kappa \rangle$.

4 Conclusions

In the present work we computed the coherent and incoherent cross sections for the neutral current neutrino-nucleus scattering off ^{95}Mo and ^{97}Mo. The cross sections have been calculated for neutrino energies appropriate for supernova neutrinos. The nuclear response of the aforementioned nuclear targets to supernova neutrinos have been estimated by folding the computed cross sections with a two-parameter Fermi-Dirac distribution. In the calculations we have adopted the wave functions which were calculated using the MQPM. For both isotopes we found that the cross section is dominated by the coherent channel.

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