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Low-Energy Neutrino Excitation of the Giant Resonance in ^{12}C

Francis J. Kelly
U. S. Naval Research Laboratory, Washington, D. C. 20390

and

H. Überall
*Physics Department, The Catholic University of America, Washington, D. C. 20017,**
and U. S. Naval Research Laboratory, Washington, D. C. 20390

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Theoretical cross sections are presented for the excitation of the giant resonances in ^{12}C by electron neutrinos with energies $E_\nu = 15-75$ MeV. Although the excitation strengths of the individual giant-resonance levels are somewhat different for the two particle-hole models used (Lewis-Walecka-deForest's and Gillet's model), the total summed cross sections are similar.

The imminent completion of the Los Alamos Meson Facility (LAMPF), and of other "meson factories" at Zürich (SIN) and at Vancouver (TRIUMPF), will render feasible experiments with electron neutrinos from stopped μ^+ mesons. At present, five proposals for such experiments have been submitted[1-5]; they are designed to test the law of lepton conservation (additive vs multiplicative), to detect neutrino-electron scattering (and possibly a neutral lepton current), and to measure cross sections of neutrino-induced nuclear reactions. Prominent targets for the latter experiments are the nuclei ^{2}H, ^{12}C, and ^{16}O, for which theoretical cross sections should be known. In addition, even for those mentioned neutrino experiments that use elementary targets, some of the proposals consider counting apparatus containing these complex nuclei; in that case, their neutrino cross sections form a background which should be known.

In our previous work, neutrino cross sections were calculated[6] for ^{2}H and[7-9] for ^{12}C. While the ^{2}H disintegration[6] and the excitation of the ^{12}N ground state from a ^{12}C target were obtained for low-energy neutrinos ($E_\nu \lesssim 100$ MeV), the giant-resonance absorption mode in ^{12}C, which represents the dominant feature in the neutrino cross section, has only been previously published by us at higher energies ($E_\nu \gtrsim 50$ MeV). However, the experiments to be carried out at the meson factories will utilize electron neutrinos from stopped μ^+ mesons whose spectrum reaches up to 53 MeV only.[10] For this reason, we present here an extension of our previous calculation[9] of the neutrino giant-resonance absorption cross section in ^{12}C to lower energies (threshold $\leq E_\nu \leq 75$ MeV).

It should be mentioned that a calculation of the neutrino excitation of all levels in ^{12}C and ^{16}O, both giant resonance and below, for low ($E_\nu \lesssim 100$ MeV) as well as high neutrino energies ($E_\nu \lesssim$ some GeV) is now in progress and will be reported by us elsewhere.

The model used in the present paper for the giant-resonance states excited in the reaction

$$\nu_e + {}^{12}\mathrm{C} \to {}^{12}\mathrm{N}_{\mathrm{g.\,res.}} + e^- \qquad (1)$$

is the particle-hole model of Gillet[11] and of Lewis and Walecka[12] and de Forest[13] (LWD). It comprises the 1^- isospin (i) state and the 0^-, 1^-, and 2^- spin-isospin (si) or spin-flip states of the giant-resonance SU$_4$ supermultiplet; the excitation of higher-spin (3^-, 4^-) giant-resonance components[14] should not be significant below $E_\nu = 75$ MeV. Table I lists the spins and parities J^π, the SU$_4$ character, the

TABLE I. Labeling of J^-, $T=1$ giant-resonance states in ^{12}C and dominant particle-hole configurations. Excitation energies are from models of Gillet (Ref. 11) and Lewis and Walecka (Ref. 12), and de Forest (Ref. 13) (LWD).

i	J	SU$_4$	ω_i (MeV) Gillett	LWD	Dominant configuration
1	1^-		17.7	19.57	$2s_{1/2}(1p_{3/2})^{-1}$
2		i	21.9	23.26	$1d_{5/2}(1p_{3/2})^{-1}$
3		si	24.2	25.01	$1d_{3/2}(1p_{3/2})^{-1}$
4			33.8	35.80	$1p_{1/2}(1s_{1/2})^{-1}$
5	0^-		24.9	25.66	$1d_{3/2}(1p_{3/2})^{-1}$
6			34.0	35.78	$1p_{1/2}(1s_{1/2})^{-1}$
7	2^-		18.2	18.91	$2s_{1/2}(1p_{3/2})^{-1}$
8			19.4	20.76	$1d_{5/2}(1p_{3/2})^{-1}$
9			23.2	23.94	$1d_{3/2}(1p_{3/2})^{-1}$

energies ω_i, and dominant configurations of these states, together with a label i. Since reaction (1) proceeds to the $\Delta T_3=+1$ nucleus ^{12}N, only $T=1$ states are included.

Figures 1 and 2 present our results for the neutrino excitation cross section σ_ν of the individual particle-hole states integrated over electron-emission angles, plotted vs neutrino energy E_ν in the low-energy region from threshold to 75 MeV. Figure 1 shows the cross sections using Gillet's model, as well as the total cross section summed over all the particle-hole states. Figure 2 shows the individual cross sections for the LWD states, and the summed total cross sections for both models. The labeling corresponds to that in Table I. It is seen that, while the excitation strengths of the individual states differ somewhat between the two models, the summed strengths are nearly the same.

Some remarks as to the reliability of these theoretical curves may be made. It is known that the particle-hole models overestimate the giant-resonance cross sections for both photoexcitation and electroexcitation[15] by a factor of about 2. Since the neutrino-excitation matrix elements are similar to those of electroexcitation, a comparable reduction may be needed for the present results to accurately predict the experimental cross sections.

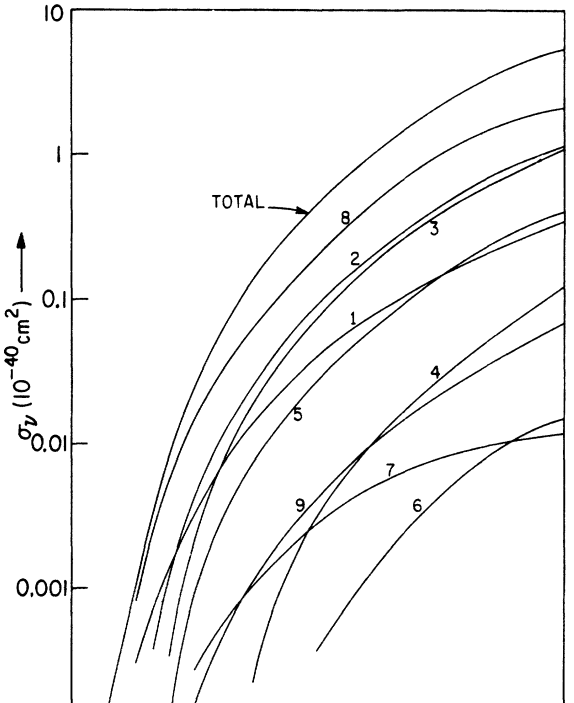

FIG 1. Cross sections of reaction (1) integrated over electron angles for excitations of the ^{12}N particle-hole states of Gillet's model (Ref. 11) and their sum total. Labeling of states corresponds to that in Table I.

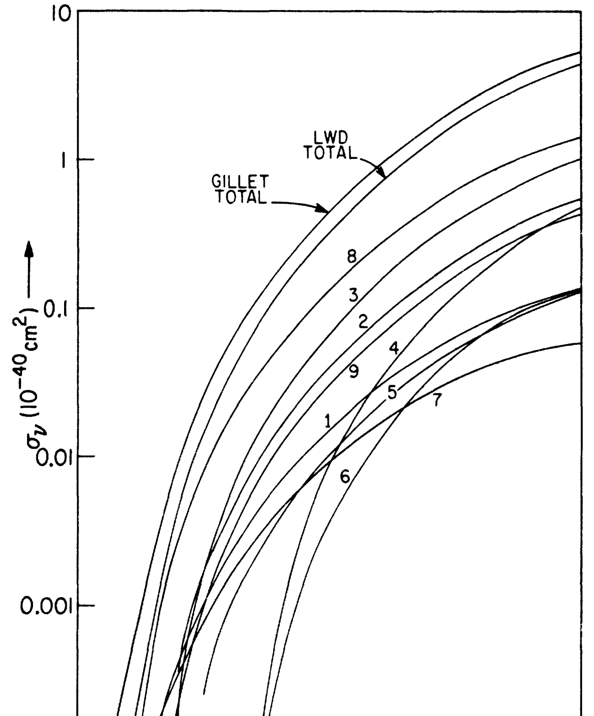

FIG. 2. Cross sections of reaction (1) integrated over electron angles for excitation of the ^{12}N particle-hole states of Lewis and Walecka (Ref. 12) and de Forest's model (Ref. 13) and sum total of LWD and Gillet models. Labeling of states corresponds to that in Table I.

The curves of Figs. 1 and 2 have been calculated using the same parameters as in Ref. 9. Because of our previous interest in high-energy applications, the energies of the states were taken strictly as given by the particle-hole models for ^{12}C, while actually, the excited states are those of ^{12}N. The latter lie higher than the ^{12}C states by about 2.2 MeV because of the Coulomb energy. This effect should lift the thresholds in Figs. 1 and 2 a little; but the total effect should not be very large. In any case, the LWD states lie about 1 MeV above the observed ^{12}C levels, and should thus be closer to reality for the neutrino reaction.

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Elastic Electron Scattering and Short-Range Correlations: A Reply to the Note by C. Ciofi degli Atti

M. Fink, H. Hebach, and H. Kümmel
Institut für Theoretische Physik, Ruhr-Universität Bochum, Bochum, West Germany

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1p1h amplitudes – usually being large – had been taken into account in the authors' paper. They vanish for self-consistent single-particle states and thus do not represent short-range correlations if the latter are defined as deviations from the self-consistent single-particle determinant.

The following statements made by Ciofi degli Atti[1] concerning our paper[2] are incorrect or require a comment:

(i) The author claims that 1p1h contributions have been put equal to zero in Refs. 2 and 3. This is wrong. We quote from Ref. 2: "We have computed the correlation contributions using $S_{\nu\mu}$ from the B-G equation for ^{16}O. This has been done by us with partial fulfillment of the self-consistency conditions." The last sentence implies that these contributions had been taken into account. Indeed, our argument was that the 1p1h terms (having their origin in the lack of self-consistency) usually are much *larger* than the true short-range-correlation (SRC) 2p2h terms. This is so even for a Woods-Saxon potential, although here the self-consistency can be achieved much better than for the oscillator.

(ii) The author did not realize that our *definition of SRC's as deviations from the self-consistent single-particle determinant* is different from his. He considers also 1p1h terms as SCR's. We do not do it, since in his definition the SRC's strongly depend on the (arbitrary) single-particle wave