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NEUTRINO DISINTEGRATION OF DEUTERIUM

S. Ying, W. Haxton, and E.M. Henley

Institute for Nuclear Theory, Department of Physics, FM-15

University of Washington, Seattle, Washington 98195

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NEUTRINO DISINTEGRATION OF DEUTERIUM

S. Ying, W. Haxton, and E.M. Henley
Institute for Nuclear Theory, Department of Physics, FM-15
University of Washington, Seattle, Washington 98195

We have calculated the rate of both neutral- and charged-current neutrino and antineutrino disintegration of deuterium.

$$\begin{aligned} &\nu + d \rightarrow \nu + n + p \\ &\bar{\nu} + d \rightarrow \bar{\nu} + n + p \\ &\nu + d \rightarrow e^- + p + p \\ &\bar{\nu} + d \rightarrow e^+ + n + n \end{aligned} \tag{1}$$

These rates are of interest for solar ^{8}B and hep (^{3}He + p) spectra and supernova neutrinos, and are relevant for the Sudbury Neutrino Observatory (SNO).

Supernova muon and tauon neutrinos have temperatures of about 10 MeV (and thus mean energies of 30 MeV). However neutrinos far out on the high energy tail of the spectrum (up to about 160 MeV) still make a nonnegligible contribution to cross sections. Thus it is clear that the calculation should include recoil effects and forbidden transition matrix elements. We have included these features, which are found to be important. We use the Paris potential to include final state hadronic interactions, and a Fermi-Dirac spectrum for neutrinos.

We begin with the standard weak interaction

$$H_w = \frac{G}{\sqrt{2}} \int \left(j_\mu J^{\mu\dagger} + h.c. \right) \, d^3x \, , \tag{2}$$

where J_μ (j_μ) is the hadron's (lepton's) weak current composed of both vector and axial vector parts, as given by the standard model. We use this interaction to compute the matrix

$$\left\langle NN \begin{pmatrix} \ell \\ \nu \end{pmatrix} \left| H_w \right| D\nu \right\rangle \, , \tag{3}$$

where $\begin{pmatrix} \ell \\ \nu \end{pmatrix}$ stand for either the charged or neutral lepton in the final state.

For the electric multipoles of the vector current, we incorporate current conservation via an extended Siegert theorem$^{1)}$; this substitution minimizes exchange current corrections. Magnetic multipole exchange currents are not small, but the contributions from magnetic multipoles of the vector current are small. For axial currents, the main exchange current corrections occur for the axial charge (time) component, but the matrix element of the axial charge is also small.

We have calculated the following cross sections in the laboratory system:

$$\frac{d\sigma}{d\omega} = \int \frac{d\sigma}{d\Omega d\omega} d\Omega \, , \tag{4a}$$

$$\sigma = \int_{\omega_{thresh}}^{\epsilon - m_\ell} \frac{d\sigma}{d\omega} d\omega \, , \tag{4b}$$

$$\langle \sigma \rangle = \int_{\epsilon_{thresh}}^{\infty} \sigma \, P_\nu(\epsilon) d\epsilon \, , \tag{4c}$$

where ω is the missing energy of the neutrino or the total energy of the two nucleons and $P_\nu(\epsilon)$ is the neutrino spectrum as a function of neutrino energy ϵ, normalized to $\int_0^\infty P_\nu(\epsilon)d\epsilon = 1$.

Previous calculations have included only the $^1S_0$ (NN) state. We include all relevant final NN states. Fig. 1 shows that states of angular momentum > 0 become increasingly important at higher energies. For 70 MeV neutrinos the cross section to P states is equal to that to S-states. At 160 MeV, the ratio is $\sim$ 5:1.

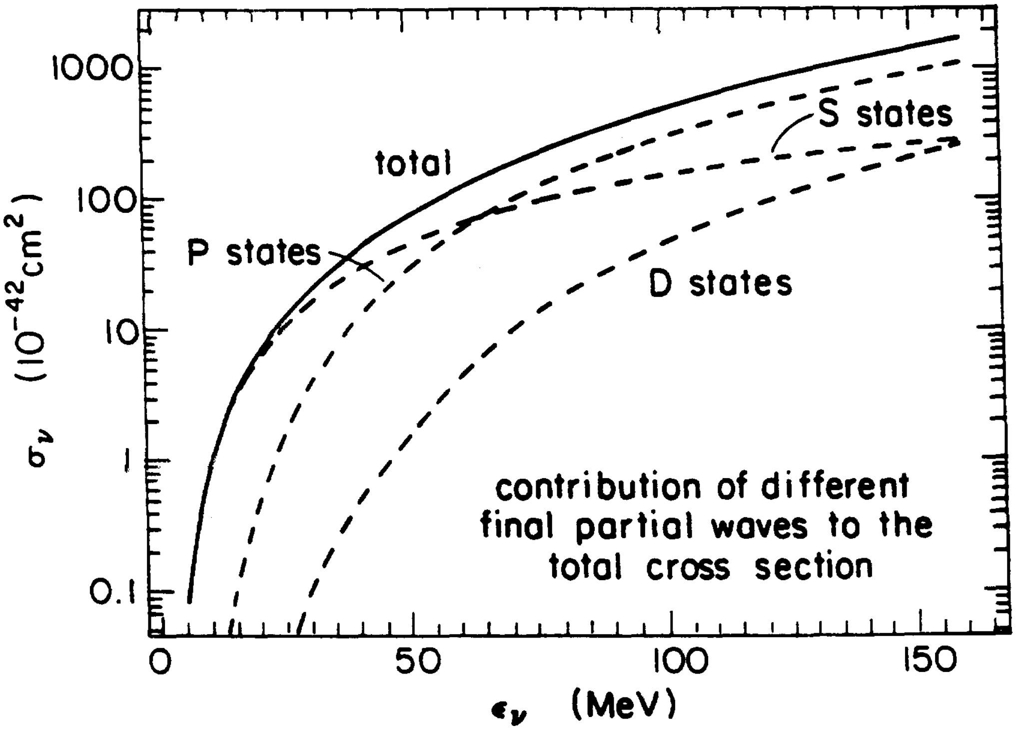

Fig. 1. Contribution of different n-p partial waves to the neutral current ν disintegration cross section.

The ratio of neutral to charged current cross sections varies somewhat with energy, and on the average is $\lesssim$ 0.5. For instance, for the ^{8}B and hep spectra, we obtain

$$\begin{aligned} &< \sigma > \; (^8\mathrm{B} - \text{neutral currents}) = 4.4 \times 10^{-43} cm^2 \\ &< \sigma > \; (^8\mathrm{B} - \text{charged currents}) = 1.2 \times 10^{-42} cm^2 \\ &< \sigma > \; (\text{hep} - \text{neutral currents}) = 1.3 \times 10^{-42} cm^2 \\ &< \sigma > \; (\text{hep} - \text{charged currents}) = 3.2 \times 10^{-42} cm^2 \end{aligned} \tag{5}$$

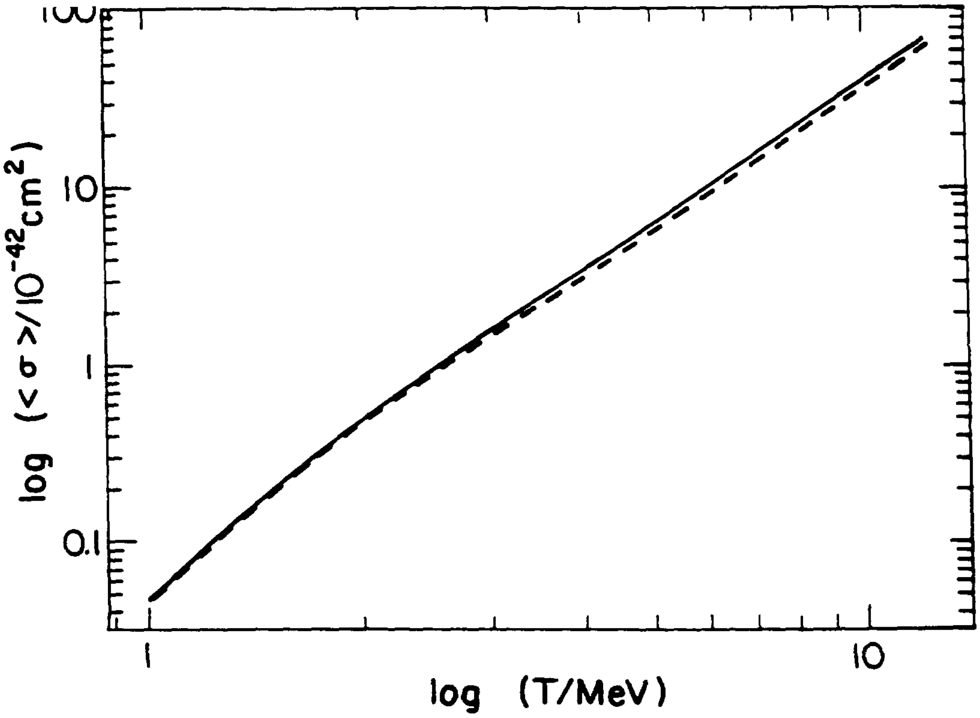

Fig. 2. Dependence of the total neutral current reaction cross section on the neutrino temperature. The solid line is for neutrinos and the dash-dotted line is for antineutrinos.

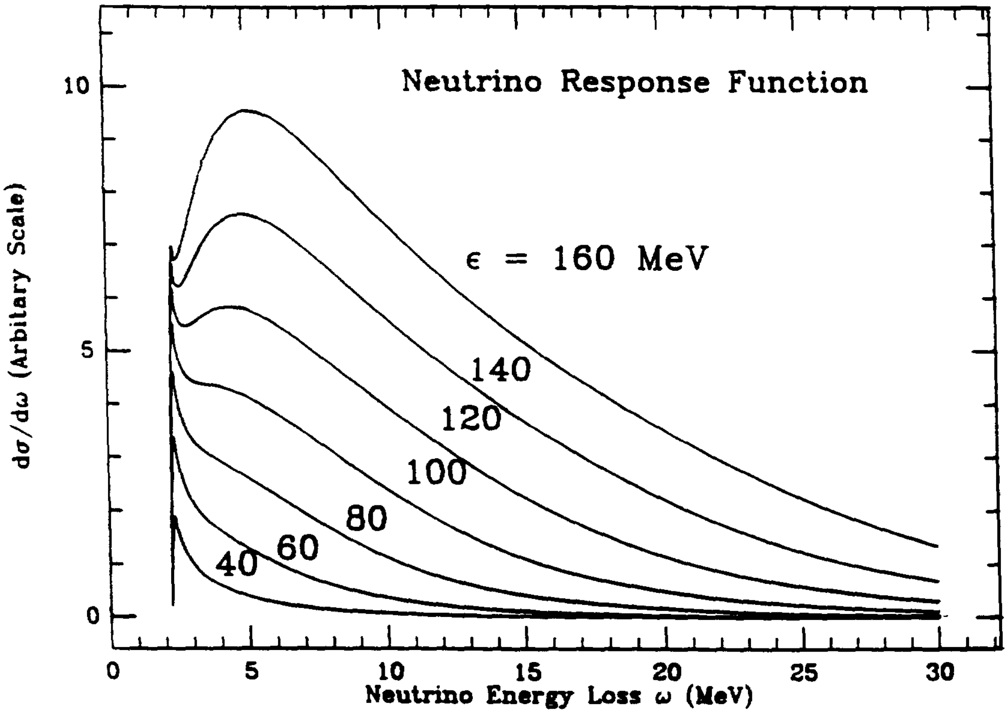

Fig. 3. The differential neutral current cross section is given as a function of neutrino energy loss for various incident neutrino energies.

The cross sections show a power law dependence on temperature for a Fermi Dirac distribution. For neutral currents, for instance, we find

$$\sigma = (a_1 T^{2.75} + a_2) 10^{-43} cm^2 \tag{6}$$

with $a_1(\nu) = 0.74$, $a_1(\bar{\nu}) = 0.65$, $a_2(\nu) = 0.21$, $a_2(\bar{\nu}) = 0.83$, as shown in Fig. 2.

The energy loss (ω) dependence of the cross section is shown in Fig. 3. At low energies it is dominated by the ${}^1S_0$ final state "resonance."

We have examined the uncertainty in our results due to the choice of hadronic NN potential by substituting the Bonn and Hamada-Johnston potentials for the Paris one. Except at low energies, where the Bonn potential gives a 7% difference due to its smaller-than-usual D-state, we find the results agree to $\lesssim$ 2%.

In summary we have carried out a careful calculation of the neutrino disintegration of deuterium for energies up to 160 MeV. We have included forbidden transitions, which are found to be important and lead to increased cross sections.

References

1. A.J.F. Siegert, Phys. Rev. 52, 787 (1937); J.L. Friar and S. Fallieros, Phys. Rev. C 29, 1645 (1984).