for nuclei spanning the entire open-shell region. Such calculations are now under way.

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Production of High-Energy Deuterons in the ^{3}He + ^{3}He Reaction and the Solar Neutrino Problem

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A spectrum of deuterons consistent with the reaction $^3\mathrm{He}+{}^3\mathrm{He}\rightarrow{}^2\mathrm{H}+{}^4\mathrm{He}+e^++\nu$ has been detected with a system sensitive to cross sections of 300 pb sr^{-1} MeV^{-1}. The measured cross section is too high for a weak-interaction process: 3.4 nb MeV^{-1} sr^{-1}. It might be due to an interaction of intermediate strength and it could explain the low flux of high-energy solar neutrinos.

Current estimates of the cross section for the reaction

$$p+p\rightarrow {}^2\mathrm{H}+e^++\nu \qquad (1)$$

predict that its detection in the laboratory is beyond present day experimental techniques.[1] Nevertheless, there is a possibility that the rate of (1) is much higher than calculated previously.[1] There are also speculations by Bahcall and Regge about the possible existence of a massive uncharged boson, capable of interacting with neutrinos with a strength 10^8 larger than that of the weak interaction.[1] Carrying such speculation one step further one might conceive that such a boson could mediate, in special circumstances, processes like (1) with much faster rates than usual for weak processes.

Among others, the reaction

$$^3\mathrm{He}+{}^3\mathrm{He}\rightarrow{}^4\mathrm{He}+{}^2\mathrm{He}\ (2p) \qquad (2)$$

reaches the ^{2}He $(2p)$ system at very low relative momenta. Subsequently ^{2}He $(2p)$ might undergo

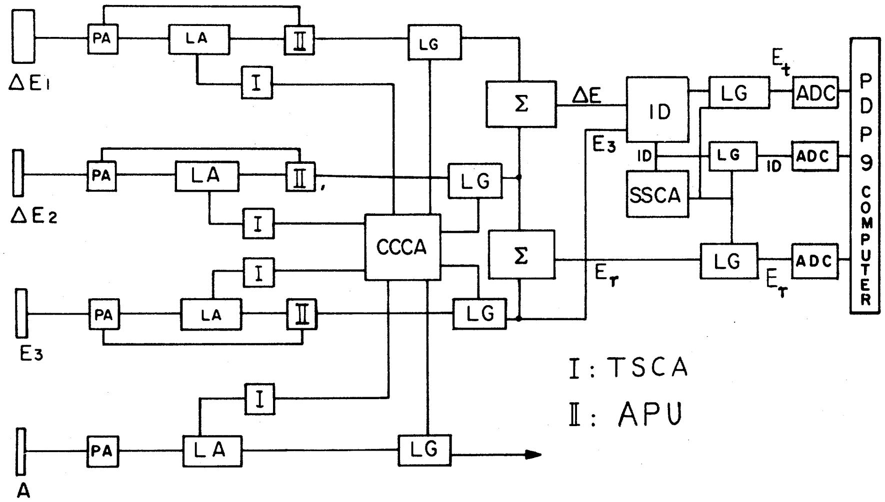

FIG. 1. Schematic of the electronics: PA, preamplifier; LA, linear amplifier; APU, anti-pileup circuit; TSCA, SSCA, single-channel analyzers; CCCA, triple coincidence-anticoincidence; LG, linear gate; Σ, sum circuit; ID, identifier; ADC, analog-to-digital converters.

the transition (1). Alternatively a "direct" reaction could take place, similar to (1):

$$^3\text{He} + {}^3\text{He} \rightarrow {}^2\text{H} + {}^4\text{He} + e^+ + \nu. \qquad (3)$$

A 13.6-MeV ^{3}He beam produced at the Van de Graaff facility of Université Laval was sent upon a ^{3}He gas target cell at a pressure of 54 Torr with 2.1-mg-cm^{-2} Havar-foil windows.[2] Reaction products were detected by a four-detector telescope, where the last detector was in anticoincidence with the first three, in order to eliminate the numerous penetrating protons and impede their pileup with reaction products stopping in the first three detectors. Detectors 1, 2, and 3 were 1000, 200, and 1000 μm thick, respectively. Approximately 10^8 p-p pairs with excitation energies below 1 MeV were projected along the solid angle of detection in 24 h. Elastically scattered ^{3}He's were stopped by an appropriate thickness of Al in order to avoid saturating the first detector of the telescope and to reduce pileup. A schematic of the electronics is shown in Fig. 1. The relevant pulses ΔE_1, ΔE_2, and ΔE_3 were used as follows: $\Delta E_1 + \Delta E_2 = \Delta E$ and E_3 were fed to an analog particle identifier, yielding an identification pulse P. A second pulse that proved very useful in providing an additional constraint in identifying the relevant particle groups was obtained by the sum $\Delta E_2 + \Delta E_3 = E_r$ (residual energy). Finally, the third pulse was simply the total energy: $\Delta E_1 + \Delta E_2 + E_3 = E_t$. The pulse E_r permits one to ascertain whether a particle, given a P labeled "deuteron" by the identifier, and having a total energy E_t, has suffered the correct energy loss in its passage through the first counter (1000 μm of Si). The accumulation of the three pulses, P, E_r, and E_t was effected on multichannel analyzers and also on-line with a PDP-9 computer and stored on magnetic tape. Figure 2(a) shows an example of a two-dimensional plot of the events in the E_t-E_r plane, with a band indicating the limits of the region of events acceptable as deuterons. The extension of the deuteron band was determined experimentally using the reaction ^{7}Li(^{3}He, d)^{8}Be, which produces a continuous spectrum. It provided also an overall test of the experimental setup. Figure 2(b) shows the identification spectrum indicating a satisfactory separation. The deuteron energy spectrum —inset in Fig. 2(a)—is consistent with the production from ^{2}He (pp) produced according to (2) and (3). No impurity that might be present in the gas target would have an adequate Q value for the production of deuterons in the energy range considered here. Spectra taken filling the target cell with air (possibly the main impurity) indicated that the observed yield originated in the ^{3}He gas.[2] The tritium impurity is $< 10^{-13}$ of the ^{3}He and besides it would give a sharp deuteron peak. Consistent with the tritium impurity limit quoted above none is observed. The average value of the measured cross section over an angular interval between 17° and 30° (17°, 20°, 25°, and 30°) is $d^2\sigma/dEd\Omega = 3.4$ nb MeV^{-1} sr^{-1}. The end points

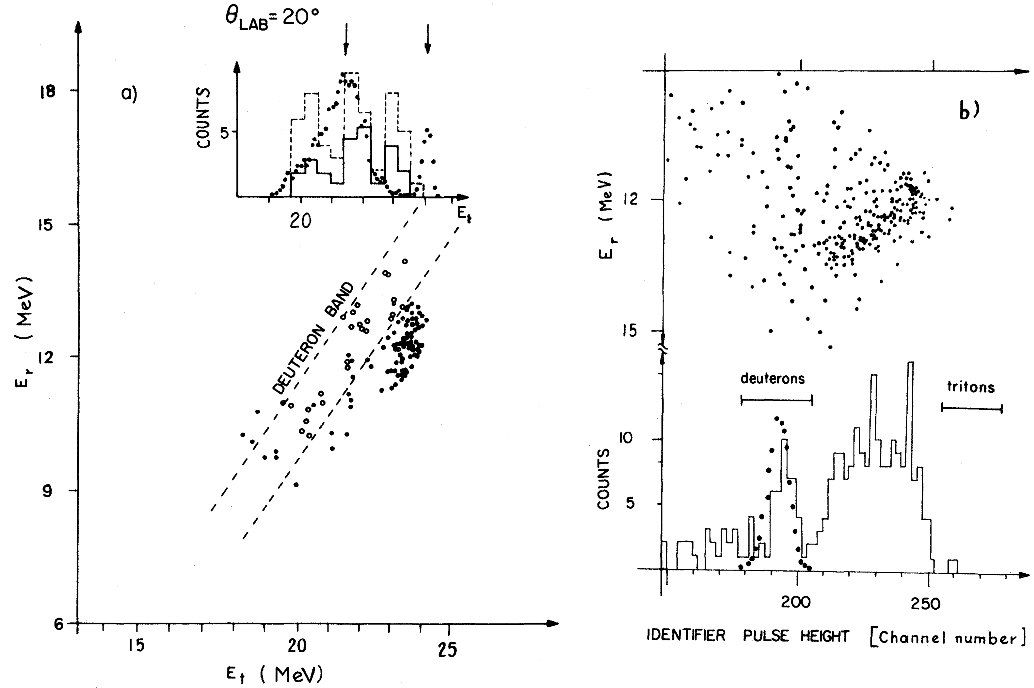

FIG. 2. (a) Two-dimensional plot of detected events on the E_t-E_r plane at 20° lab. Open circles satisfy both criteria set to accept "good" events as stated in the text. They fall within the *deuteron region* of the identification spectrum shown in (b) and the *deuteron band.* Solid circles do not fall within the deuteron window indicated in (b), and are thus rejected. The inset provides a projection of the spectrum of the deuteron band. The dashed histogram is the sum total of two runs. The dots in the inset correspond to a calibration spectrum from $^7Li(^3He,d)^8Be$; the arrows indicate the ground and first excited states. Spectra from this reaction between 20° and 55° lab served to calibrate the scales of both E_t and E_r. (b) Identification spectrum. The E_t-P two-dimensional plot and projection into the P axis. The separation of the deuteron pulses from other pulses is considered to be unambiguous. The dots show the identification spectrum of the reaction $^7Li(^3He,d)^8Be$ corresponding to the energy shown in (a) for the same reaction. The histogram is the sum of total of two runs.

of the measured spectra are consistent with the kinematics of Reaction (2) and/or (3), as shown in Fig. 3.

In addition to the continuum of deuterons another type of "particle" is conspicuous in Fig. 2, more intense and with a rather well-defined energy. The corresponding identification spectrum is rather broad and it lies between the deuteron and triton identification regions. This is consistent with the detection of two protons of approximately the same energy arriving simultaneously at the detector telescope: $P(2p)=2^n P(p)$, where $n=1.7$, thus $P(2p)=3.20P(p)$,[3] in fair agreement with the group shown in Fig. 1. The well-defined energy is the consequence of the cutoff introduced by the ΔE thickness on the proton detection and of discriminators set to reduce their intensity. In addition to the use of anti-pileup circuits which rejected pulses within 200 nsec, tests were made reducing the beam intensity to 0.4 of the current normally used. No evidence of pileup resulted from these tests.

The implications of the results reported here are not straightforward because $^2He(2p)$ is prepared through an intermediate reaction. However they do indicate that it is possible that Reaction (1) indeed proceeds at a higher rate than has been calculated, consequently explaining the reduced production of high-energy neutrinos from the sun. Alternatively a process of strength intermediate between hadron and weak interactions may exist and account for the production of deuterons in the $^3He+{}^3He$ interaction. The measured cross section is too small (by 10^{-7}) to be a typical strong-interaction process, and too large (by about 10^8) to be a conventional weak-interaction process.

If the observed deuterons stem from a sequence

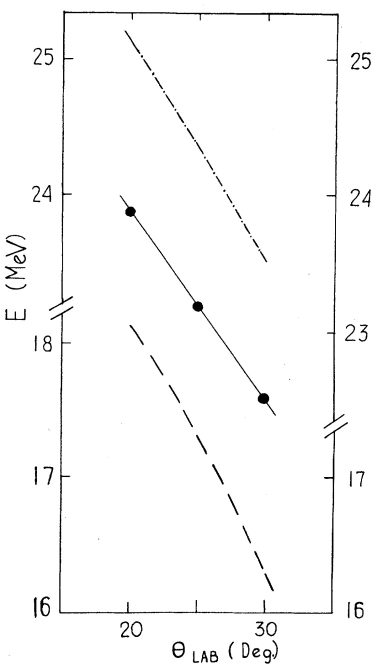

FIG. 3. Kinematics of the endpoint of the reaction $^3He(^3He, 2p)^4He$ (dash-dotted line) and of the measured deuteron spectra (solid line). The dashed line indicates the highest energies of deuterons produced as secondaries by the elastic ^3He's in the Al degrader; 19.8 MeV is an upper limit for deutrons that could be produced in *any known gaseous element* other than ^3H. Notice that the vertical scale is interrupted and suppressed by 5 MeV.

given by (2) and (1) there are uncertainties because the final-state ^2He (pp) peak (which is asymmetric and favors low relative momenta) may be distorted. For example, vacuum-polarization effects can change considerably the number of ^2He at very low energies.[4] There is no experimental work done with sufficiently high resolution in this region of the spectrum for the purpose of investigating distortions, yet it may provide precious information on the ^2He wave function, and indicate whether the extrapolation of p-p scattering to very low energies (< 100 keV) is valid. Direct study of the very low-energy p-p nuclear scattering seems to be out of the question due to the Coulomb attenuation.

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Note added. — While this report was being written several publications have appeared about a heavy-particle resonance coupled to e^+e^- pairs and to hadrons.[5] It is too early to assess the possible implications for the problem at hand, but second-order processes mediated by this resonance (or else by the hypothetical neutral boson) might provide an explanation for the dynamics of the above mentioned intermediate-strength field.

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