of $K^{\pm}D$ total cross-section difference (also dominated by ω exchange) gives[18] $\alpha_{\omega}(0)=0.41\pm0.03$.

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Search for High-Energy Deuterons in the $^3He + {}^3He$ Reaction and the Solar Neutrino Problem

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As the result of a recently reported experiment, a search has been made for deuterons from the reaction $^3He + {}^3He \rightarrow \alpha + d + e^+ + \nu$. Two independent experiments were done at $E_{He} = 15$ and 25 MeV. In both cases, upper limits were obtained which are about a factor of 20 below the previously measured cross section (3.4 nb/MeV sr).

In a recent Letter,[1] Slobodrian, Pigeon, and Irshad (SPI) reported a cross section of 3.4 nb/MeV sr for the reaction $^3He + {}^3He \rightarrow {}^4He + d + e^+ + \nu$. Such a cross section is too large by about a factor of 10^8 [1,2] to be a conventional weak-interaction process but might explain the low flux of high-energy solar neutrinos observed in experiments by Davis *et al.*[3] That a small increase in the $p+p$ cross section would indeed explain the absence of high-energy solar neutrinos was shown by Newman and Fowler,[2] who also argued that a cross section of 3.4 nb/MeV sr was completely incompatible with current models of solar structure and with the experimental literature on β-decay rates. Since the consequences of such an increase in the p-p rate are so fundamental to our understanding of β decay and solar astrophysics, we felt it was important to verify the results of SPI in an independent experiment.

We have searched for deuterons from the reaction $^3He(^3He, de^+\nu)^4He$ in two different ways: (i) by using a three-counter telescope similar to that used by SPI, and (ii) by using a magnetic spectrometer. In the first experiment, a 25-MeV $^3He^{++}$ beam from the upgraded Chalk River MP tandem accelerator bombarded a ^3He gas target[4] operated at a pressure of 230 Torr. Reaction products were detected in a three-counter telescope consisting of a 1000-μm-thick Si (ΔE_1) detector, a 700-μm (ΔE_2) detector, and a 2000-μm Si (E) detector. An aluminum absorber was placed in front of the telescope to stop elastically scattered ^3He particles. The telescope was calibrated with the reaction $^{14}N(^3He, d)$. Data collected at 28° and 30° from the beam were recorded event by event for later analysis. These angles are near a maximum in the $^3He(^3He, pp)^4He$ cross section.[5] On playback, two independent particle identifications (PI) were obtained for each particle: PI1 is $R(\Delta E_1 + \Delta E_2 + E) - R(\Delta E_2 + E)$ and PI2 is $R(\Delta E_2 + E) - R(E)$, where $R(x)$ is the particle's range at energy x. The results are shown in Fig. 1 for the data taken at 30°.

Deuterons coming from ($^3He, d$) reactions on residual air in the gas cell were observed in the energy window from 23.5 to 30.5 MeV. However, no deuterons were observed in the energy window above 30.5 MeV; the kinematic end point of the reaction $^3He(^3He, 2p)^4He$ is 33.0 MeV. The diagonal band of particles that cuts the lower right-hand corner of the deuteron region in Fig. 1(c) is made up of events in which two high-energy protons that cannot be stopped in the E detector (i.e., $E_p > 22.5$ MeV) enter the counter telescope simultaneously. This is the only type of random proton coincidence event not completely rejected by the mass-identification system used in the pres-

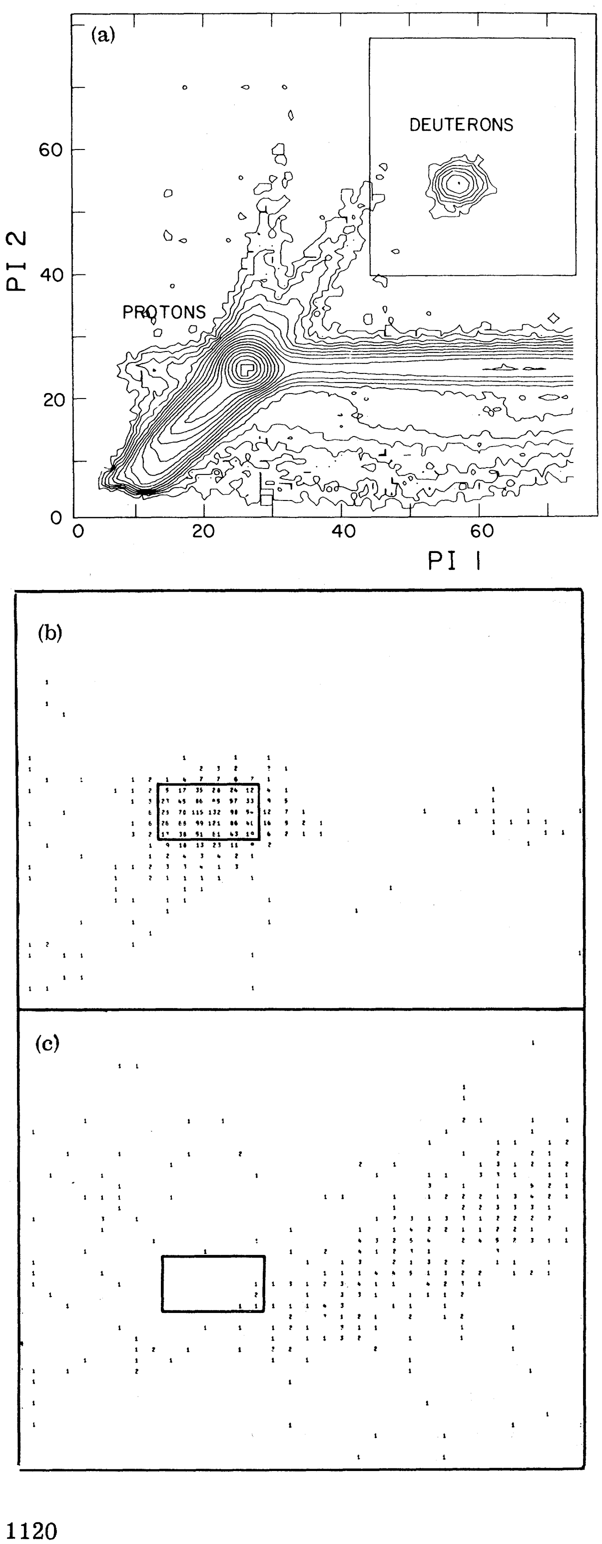

FIG. 1. (a) Log_2 contour plot of PI2 vs PI1 in the energy window 23.5 to 30.5 MeV. The lowest contour represents two counts. The band extending to the right of the proton pole results from random coincidences in which one particle, usually a proton, stops in the ΔE_1 detector and the second, a proton, is identified as such by the $\Delta E_2 + E$ system. (b) Expanded view of the box in (a) for the energy window from 23.5 to 30.5 MeV. Single events are shown and 90% of the deuterons are inside the window indicated. (c) Same as (b) but for an energy window between 30.5 and 35 MeV. The diagonal band to the right of the deuteron window is discussed in the text. Five counts appear in the lower right-hand corner of the window.

ent experiments. By combining the data at 28° and 30° we obtain an upper limit of 0.2 nb/MeV sr for the reaction ^{3}He(^{3}He, $de^+\nu$)^{4}He at $E_{^3\mathrm{He}} = 25$ MeV.

In order to overcome the limitations imposed by these random proton coincidences, we repeated the experiment using the quadrupole-triple-dipole (QDDD) magnetic spectrometer,[6] since the highest-energy protons that can be produced via the ^{3}He + ^{3}He reaction have a rigidity well below that of the lowest-energy deuterons of interest.

In the QDDD experiment the gas cell, operated at a ^{3}He pressure of 760 Torr, was bombarded with a beam of 15-MeV ^{3}He^{++} ions. Reaction products were analyzed by the QDDD spectrometer and detected by a 70-cm-long Charpak counter with 2-mm wire spacing.[7] The spectrometer, which was positioned at a lab angle of 20°, operated with a solid angle of 11 msr. Position and ΔE information were recorded event by event in the PDP-10 computer. Since Charpak counters are also sensitive to neutrons and γ rays, a number of measures were taken to reduce the background in the vicinity of the focal plane. The experiment was done in a cycle consisting of (i) a calibration run with the reaction ^{7}Li(^{3}He, d)^{8}Be, (ii) a background run with the spectrometer valve closed, and (iii) a data collection run with the valve open and the same integrated charge as (ii). This cycle was repeated several times for each of two magnetic-field settings to cover the deuteron energy range from 22 to 27 MeV. Periodic measurements were made of the background with the beam off to correct for differences in running time; these corrections were always very small.

The results are shown in Fig. 2. It is seen that

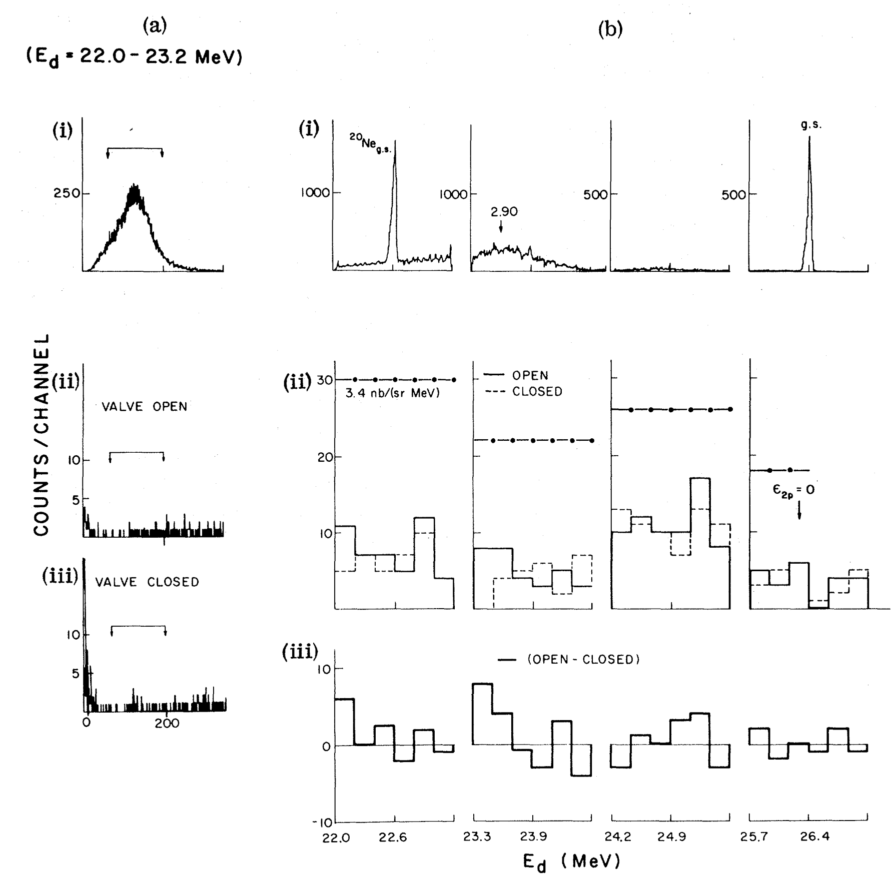

FIG. 2. (a) Energy-loss spectra from Charpak counter: (i) for the calibration reaction ^{7}Li(^{3}He,d)^{8}Be, (ii) for the ^{3}He + ^{3}He reaction with spectrometer valve open, and (iii) same as (ii) with valve closed. The arrows indicate the ΔE window used to analyze the data. (b) Position spectra from the Charpak counter: (i) calibration reactions ^{19}F, ^{7}Li(^{3}He,d)^{8}Be, ^{20}Ne for the indicated deuteron energy regions; (ii) position spectra with valve open and closed as well as the number of counts expected assuming a 3.4-nb/MeV · sr cross section for the reaction ^{3}He(^{3}He,$de^+\nu$)^{4}He; (iii) difference spectrum. The arrow labeled $\epsilon_{2p} = 0$ denotes the maximum kinematically allowed deuteron energy which corresponds to zero relative p-p energy.

in all cases the number of counts recorded with the valve open was not significantly different from that with the valve closed. The cross sections corresponding to four regions of excitation shown in Fig. 2 are 0.17 ± 0.22, 0.25 ± 0.23, 0 ± 0.45, and $0\ ^{+0.37}_{-0.55}$ nb/MeV sr. These results are consistent with a 50% probability that the cross section is less than 0.17 nb/MeV sr and an 85% probability that it is less than 0.4 nb/MeV sr.

Since the upper limits obtained in the present experiment for production of deuterons from the reaction $^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + d + e^+ + \nu$ are about a factor of 20 below the cross section (3.4 nb/MeV sr) obtained by SPI one must cast serious doubt on the suggestion that the $p+p$ cross section at solar energies is in error. It should also be mentioned that Bardin and co-workers[8] recently obtained a similar upper limit (≤ 0.3 nb/MeV sr) for the reaction $t + t \rightarrow {}^4\mathrm{He} + d + e^- + \bar{\nu}$.

Finally we offer the following comment on a method of mass identification that does not make an independent identification based on the energy loss in the ΔE_2 counter. A careful analysis of this method reveals a region where the random coincidences of two protons are indistinguishable from real deuteron events. A specific example is $E_{p_1} = 4$ MeV and $E_{p_2} = 18$ MeV. Here the analog identifier would give an output signal that corresponds exactly to that of a deuteron, i.e., $R(\Delta E_1 + \Delta E_2 + E) - R(E) = 1200$ μm of Si with $E_r \equiv \Delta E_2 + E = 12.19$ MeV and $E_t \equiv \Delta E_1 + \Delta E_2 + E = 22.0$ MeV. From Fig. 2 of Ref. 1 it is seen that such an event would lie in the center of the "deuteron band." Such an event would have been rejected by our identification system since the 4-MeV proton stops in the ΔE_1 counter, but the second would be identified by PI2 as a proton. Using a computer simulation of the experiment of SPI we find events of this type covering the whole "deuteron band." This then could be the explanation for the large cross section quoted by them.

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