The Search for High-Energy Deuterons in the $^3\text{He}+^3\text{He}$ Reaction (*).

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Summary. — High-energy deuterons have been detected from the $^3\text{He}+^3\text{He}$ reaction with a system sensitive to cross-sections of 0.6 nb sr$^{-1}$. Several tests have permitted to evaluate the small contribution of spurious events. The deuterons are kinematically consistent with the reaction $^3\text{He}+^3\text{He} \rightarrow ^2\text{H}+d\text{He}+e^++\nu$, but the measured cross-section at 20$^\circ$ laboratory is too high for a weak-interaction process: $(1.3 \pm 0.3)$ nb sr$^{-1}$. It might be due to an interaction of intermediate strength causing the decay of pp pairs ($^3\text{He}$) into deuterons. Other alternatives and the implications concerning fusion processes and the production of neutrinos in the Sun are discussed in the text.

1. — Introduction.

The generation of elements in stars begins with the formation of deuterons resulting from the reaction of two protons

$$H(p, e^+\nu)^2\text{H}, \quad Q_\beta = 0.420 \text{ MeV}. \quad (1)$$

At the temperature in the centre of the Sun ($\approx 15 \cdot 10^6$ K), the relative energies of the protons are of the order of one keV. The reaction rate is the result (1) of the tunnelling of charged particles, from the high-energy tail of a Maxwellian

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velocity distribution, through a much higher Coulomb barrier ($\simeq 0.5 \text{ MeV}$). The cross-section at the most effective energy, or Gamow peak, of $6 (\text{keV})^2$ is estimated to be $\sim 10^{-26} \text{b}$ ($^2_2$), a measurement which is beyond the present-day experimental capabilities. One could, however, look for an alternative way of studying the pp reaction. This is possible, for example, by an investigation of the reaction $^3\text{He}(^3\text{He}, ^2\text{He})^4\text{He}$, where two protons are produced at low relative momenta within the range of nuclear forces.

A first report on the study of this reaction has been published previously ($^4$). The conclusions of the investigation were: 1) the experimental spectra are consistent with the production of high-energy deuterons according to the reaction

$$^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + ^2\text{H} + e^+ + \nu, \quad Q = 13.28 \text{ MeV};$$

2) this result indicates that the pp reaction might proceed at a higher rate than has been calculated, consequently explaining the reduced production of high-energy neutrinos from the Sun ($^4$).

A second experiment ($^5$) was carried out to verify, whether other processes might yield deuterons; it covered the possible contributions from a ($^1\text{H}, ^3\text{H}$) reaction, an (elastic $^3\text{He}, ^2\text{H}$) reaction and a ($^2\text{H}, ^2\text{H}$) reaction induced by tritons produced on the Havar entrance foil of the gas cell. According to Newman and Fowler ($^6$), there is little reason to expect reaction (2) to behave differently from similar $\beta$-decays, and a solar model compatible with solar luminosity and radius does not permit a large enhancement factor of the p-p rate. Davies et al. ($^7$) searched for deuterons from $^3\text{He} + ^3\text{He}$ collision in two experiments. The first with a three-counter telescope and an $25 \text{MeV} \hspace{1mm} ^3\text{He}^+$ beam resulted in an upper limit of $0.2 \text{ nb (MeV)}^{-1} \text{sr}^{-1}$. The second experiment used a quadrupole-triple-dipole magnetic spectrometer and a beam of $15 \text{ MeV} \hspace{1mm} ^3\text{He}^+$ ions, the cross-sections of the spectrum divided in four ranges were lower

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($) Comments concerning ref. (7): 1) There is a discrepancy between the third cross-section of null value on p. 1122 and the resultant number of counts [2] estimated from the third spectrum in fig. 2b) (iii). 2) On the same page, the factor 20 compares the $3.4 \text{nb (MeV)}^{-1} \text{sr}^{-1}$ cross-section value with their measured values and not with their upper limits. 3) Error bars for sections of a spectrum are less advantageous than the error bar for the counts of an integrated spectrum. The uncertainty in energy is not a relevant information in order to establish the phenomenon under study.