Comment on "Fusion of Polarized Deuterons"

The recent Letter by Hofmann and Fick[1] claims that the polarized $d+d \rightarrow n+{}^3\mathrm{He}$ fusion reactions in the center-of-mass energy range 20–150 keV are not suppressed in their refined resonating-group calculations. This finding, if correct, would render unfeasible the idea of a "neutron free" fusion reactor based on the polarized deuterons.[2] In their conclusion, it was argued that the large $s=2$ (quintet spin) channel contribution is attributed to the presence of a D-state component in ^{3}He which allows transition from the polarized entrance channel via the strong central force. This argument seems implausible. In order for the central force to contribute to the matrix element $\langle {}^3D_2, {}^1D_2 | \sum_{i<j} V_{ij}^C | {}^5S_2 \rangle$ between the $^5S_2$ dd channel and the $^3D_2$ and $^1D_2$ n-^{3}He channel, pairs of nucleons in different deuterons must be in the relative D wave to "match up" with the D-wave component in ^{3}He. This is so because (a) the D state in the deuteron is neglected, (b) the central force does not change the relative orbital angular momentum, and (c) the orthogonality condition dictates this when the central force acts on another pair of nucleons. Since the incoming dd is in the relative S wave, the D-wave composition between pairs of nucleons in different deuterons as obtained from the partial wave exansion of the dd relative S wave upon coordinate transformation is smaller than the corresponding S-wave composition. With the latter contributing substantially to the unpolarized cross section plus the fact that the D-state probability in ^{3}He is merely $\sim 4\%$ and the fact that the short-range central force yields a larger matrix element for the relative S wave than for the relative D wave, we do not see any reason that this $\langle {}^3D_2, {}^1D_2 | \sum_{i<j} V_{ij}^C | {}^5S_2 \rangle$ matrix element could be of any appreciable size as compared to the $\langle {}^1S_0 | \sum_{i<j} V_{ij}^C | {}^1S_0 \rangle$ matrix element. On the basis of the above reasonings, we estimate that the ratio of the polarized to the unpolarized cross section due to the central force should be $\sim 10^{-3}$–10^{-4}. This is much smaller than those obtained in Ref. 1.

To verify our point, we carried out a distorted-wave Born-approximation (DWBA) calculation. Since the experimental reaction cross sections are two orders of magnitude smaller than the elastic dd and n-^{3}He cross sections, the DWBA should be reasonably good. The same nucleon-nucleon interaction[3] as used in Ref. 1 is adopted to calculate the matrix elements. The calculated unpolarized cross sections $d+d \rightarrow n+{}^3\mathrm{He}$ and their angular distributions at these low energies in our DWBA calculation are quite in accord with the experimental data.[4] This justifies our approximation.

It turns out, as expected, that the central force offers little contribution to the polarized cross sections. As a result, we predict that the central force yields polarized cross sections which are $\sim 1.3\times 10^{-4}$ times that of the unpolarized cross sections. This agrees well with our earlier estimate and is in contradiction with the results of Ref. 1.

The spin-orbit and tensor interactions, on the other hand, yield larger contributions to the polarized cross sections. However, according to our calculations, these spin-dependent interactions give polarized cross sections which are $\sim 7.7\%$ of the unpolarized ones in this low-energy region. This is still much smaller than those predicted by Ref. 1 and the R-matrix analysis.[5]

Another point we want to raise concerns the tensor analyzing power. It was pointed out in Ref. 1 that without the contribution of the $s=2$ channel, the angular distributions of T_{20} and T_{22} (A_{zz} and A_{xx-yy}) should be symmetric with respect to 90° and T_{21} (A_{xz}) antisymmetric with respect to 90°. This is correct. But contrary to what was implied in Ref. 1, the experimental results[6] in $^2H(d_{\mathrm{pol}},n)^3$He do not seem to show very large asymmetries in these analyzing powers at $E_d = 320$ keV. It is also stated in Ref. 1 that iT_{11} (A_y) should vanish at 90° if the $s=2$ channel does not contribute. This is not correct, since without the $s=2$ channel there is still a $P_1^1(\cos\theta)=\sin\theta$ in iT_{11} (A_y) due to the spin-triplet to spin-singlet transition which does not vanish at 90°. Therefore, the experimentally nonvanishing iT_{11} (A_y) results[7] at 90° do not have direct bearings on the presence of the $s=2$ channel, unless the triplet-to-singlet transition is negligible in the final-state interaction between n and ^{3}He.[7]

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