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Communications

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Trineutron problem clarified

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The longstanding disagreement between the predictions of Faddeev and variational calculations on the existence of the trineutron is shown to arise from the potentials used and is not attributable to the difference in approach.

[NUCLEAR STRUCTURE ^3n; confirmed nonexistence. Faddeev-UPE method.]

Disagreement lingers in theoretical few-nucleon physics about the existence of the trineutron. Mitra and his coworkers[1] contend that their separable-potential treatment of the system predicts a bound three-neutron cluster. On the other hand, Okamoto and Davies,[2] Barbi,[3] and Bell and Delves[4] charge that their variational calculations deny the claims of Mitra *et al.* At one juncture, it appeared that the issue would be resolved in favor of the pro side by the supporting experimental data of Adjacic *et al.*[5] but the absence of corroborating evidence obtained by other groups in the ensuing years has now reversed that decision. Thus, although the situation is now clear cut on the experimental side, the puzzling disparity between the predictions of the two sets of computations remains a nagging problem.

We sense that among few-nucleon theorists there is a consensus which recognizes that the Faddeev calculations of Mitra relied heavily on central separable potentials, noteworthy for their overbinding effects in the triton[6] and that the disagreement can be laid to this source. However, confirmation of this supposition has not been forthcoming because, surprisingly, no one has yet performed a Faddeev calculation using the same local potentials employed by the variationalists. We believe the time is here and the work we report in this paper, a spin-off from our molecular calculations on fermionic helium trimers,[7] will help settle the issue of the existence of ^3n, at least from the theoretical point of view.

To enter into the details of our calculations, we reiterate that the state most favorable towards binding the trineutron is the $^2P_{1/2}$ odd-parity state suggested by the shell model.[3] For this configuration of ^3n, an appropriate Faddeev-unitary-pole-expansion (UPE) analysis,[7,8] in which spin and statistics are explicitly included and the method of Harms is used to convert the local potentials to separable form,[9] leads to the coupled integral equations

$$\xi_{10}(p)=\iint\Big[-\tfrac{1}{2}[\tfrac{1}{2}(p^2+p'^2)+\tfrac{5}{4}pp'y]g_1^t(Q)g_1^t(Q')\Big(E_T-\frac{1}{m}(p^2+p'^2+pp'y)\Big)^{-1}\tau_1^t(p')\,\xi_{10}(p')$$
$$-\frac{\sqrt{3}}{2}(p'+\tfrac{1}{2}py)Q^{-1}g_1^t(Q)g_0^s(Q')\Big(E_T-\frac{1}{m}(p^2+p'^2+pp'y)\Big)^{-1}\tau_0^s(p')\,\xi_{01}(p')\Big]\frac{p'^2dp'}{2\pi^2}\,dy\,,$$

$$\xi_{01}(p)=\iint\Big[-\frac{\sqrt{3}}{2}(p+\tfrac{1}{2}p'y)Q'^{-1}g_0^s(Q)g_1^t(Q')\Big(E_T-\frac{1}{m}(p^2+p'^2+pp'y)\Big)^{-1}\tau_1^t(p')\,\xi_{10}(p')$$
$$-\tfrac{1}{2}y\,g_0^s(Q)g_0^s(Q')\Big(E_T-\frac{1}{m}(p^2+p'^2+pp'y)\Big)^{-1}\tau_0^s(p')\,\xi_{01}(p')\Big]\frac{p'^2dp'}{2\pi^2}\,dy\,,$$

where $\xi_{l\Lambda}(p)$ is the $l\Lambda$th component of the spectator function for the three-body system, l is the pair angular momentum, Λ is the spectator relative angular momentum, $g_l^{s,t}$ is the s- ($l=0$) or p- ($l=1$) wave spin singlet or triplet two-body form factor, $\tau_l^{s,t}$ is the propagator defined by

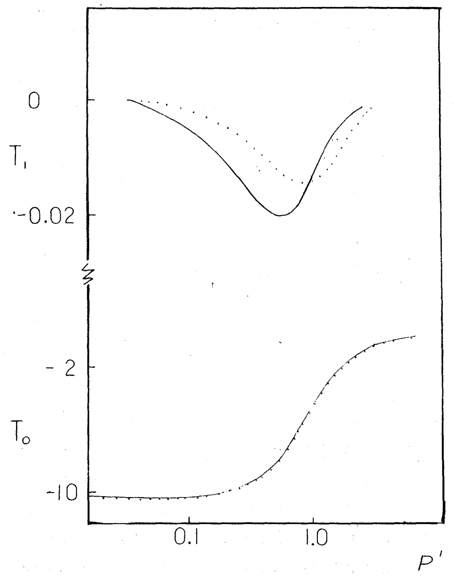

FIG. 1. Plot of the exact (full curve) and 1-term UPE (dotted curve) s- and p-wave two-body off-shell t matrices, $T_0(p,p',s)$ and $T_1(p,p',s)$ respectively, for the spin-averaged Rarita-Present potential with $p = 0.021\ \mathrm{fm}^{-1}$ and $s = 0.0\ \mathrm{fm}^{-1}$.

$$\tau_l^{s,t}(p') = -\left\{\lambda_l^{s,t} + \int_0^{\infty} [g_l^{s,t}(q)]^2 \times\left(E_T - \frac{3}{4}\frac{p'^2}{m} - \frac{q^2}{m}\right)^{-1} q^2\,dq\right\}^{-1},$$

$\lambda_l^{s,t}$ is the eigenvalue from the homogeneous Lippmann-Schwinger equation,[9] y is $\cos\theta_{\vec{p}\cdot\vec{p}'}$, Q is $|\frac{1}{2}\vec{p}+\vec{p}'|$ and Q' is $|\vec{p}+\frac{1}{2}\vec{p}'|$.

The coupled equations were converted to matrix-eigenvalue problems using the discretization afforded by quadrature and were solved by matrix inversion.[8] The angular integrals and momentum integrations were performed with 16-pt Gauss-Legendre quadratures. Values of the form factors required at other than pivotal points were obtained by cubic-spline interpolation. The local potentials used are the Rarita-Present singlet and triplet central potentials whose parameters are quoted in Ref. 3. Because the UPE is quickly convergent (see Fig. 1 and Ref. 10, where the UPE is discussed in great detail) and we are not seeking the greatest accuracy in our calculations, we used only one term in the separable expansion for the local potentials.

We could not extract a negative value for E_T, the three-body binding energy. We found a matrix eigenvalue of only 0.24, when E was set equal to zero. Any improvements, either by the inclusion of more terms in the UPE or of higher partial waves (Kok, in his dissertation,[11] has shown that d and higher partial waves contribute only fractionally to the triton binding energy), are unlikely to bridge the large gap between the obtained eigenvalue and unity. We are irresistibly drawn to the conclusion that ^3n does not exist and that our results uphold the position of the variationalists. Our work should allay any fears that the Faddeev method has failed in ^3n. Indeed, it confirms that the consensus on Mitra's result—that his separable potentials overbind—is well-founded. In closing, we note that the trend of our results even allows us to hazard a guess that ^4n is not bound.

Glockle's paper[12] has now appeared in print. His results completely support ours.

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