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EVIDENCE FOR A STRONG THREE-BODY FORCE IN THE TRITON*

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In view of the fact that three-body calculations with apparently "realistic" two-nucleon potential models underbind ^{3}He by about 1.7 MeV and produce only rough agreement with its charge form factor, it appears necessary to make some changes in our theoretical assumptions. In this work we shall investigate the possibility that these discrepancies are due, not to off-shell effects, but to the existence of a strong three-body force. Specifically, we shall utilize the existing charge form factor data for ^{3}He, ^{3}H and some assumptions to produce a model of the triton wave function compatible with these constraints. Given this wave function, the Schrödinger equation may be trivially solved for the effective local potential. The discrepancy between this potential and those predicted by typical pair-interaction models in the domain where all three particles are close together appears to provide clear evidence of a strong attractive three-body force.

To proceed we shall assume that the wave functions for ^{3}He, ^{3}H are identical and describe a purely L=0 state. The relation between the experimental input and this wave function is given by

$$\begin{aligned} F_{ch}(^3\mathrm{He}) &= \left(f_p + \tfrac{1}{2} f_n\right)(F_1 + F_3) - \tfrac{1}{3}(f_p - f_n)\, F_2 , \\ F_{ch}(^3\mathrm{H}) &= \left(f_p + 2f_n\right)(F_1 + F_3) + \tfrac{2}{3}(f_p - f_n)\, F_2 , \end{aligned} \tag{1}$$

where F_1, F_2, F_3 are the body form factors and f_p, f_n the charge form factors of proton and neutron, respectively. All quantities in eq. (1) are functions of q^2, the momentum-transfer. It is convenient to employ the following parametrization of the ^{3}He, ^{3}H charge form factors:

$$F_{ch}(q^2) = e^{-a^2q^2} - b^2q^2\, e^{-c^2q^2} + d\left\{ e^{-\left(\frac{q-q_0}{p}\right)^2} + e^{-\left(\frac{q+q_0}{p}\right)^2} \right\} . \tag{2}$$

For ^{3}He we shall use the parameters determined by McCarthy et al.[1)] in the analysis of their experiment. In the case of ^{3}H, experiments only cover the range $q^2 \lesssim 8$ enabling one to determine only the a, b, c parameters in this formula. However, guided by the ^{3}He data, model calculations, and a comparison of ^{3}He and ^{3}H in the measured region, we shall assign what we believe are reasonable

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values to the d, q_0, p parameters for ^3H, as listed in Table 1.

TABLE 1: Parameters for ^3He, ^3H Form Factors

	a	b	c	d	q_0	p
^3He	.67500	.36600	.83600	-.00678	3.980	0.900
^3H	.59914	.34623	.70007	-.00680	4.162	0.950

In fig. 1 we have plotted the absolute values of ^3He, ^3H form factors determined by these parameters. In order to eliminate the uncertainty introduced by extending the ^3H curve in this fashion we have actually performed our analysis for a broad band of possible ^3H curves centered about this choice. These studies indicate that the sum of all experimental uncertainties affecting the curves of fig. 1 produces a net effect of at most 4-5% in our results.

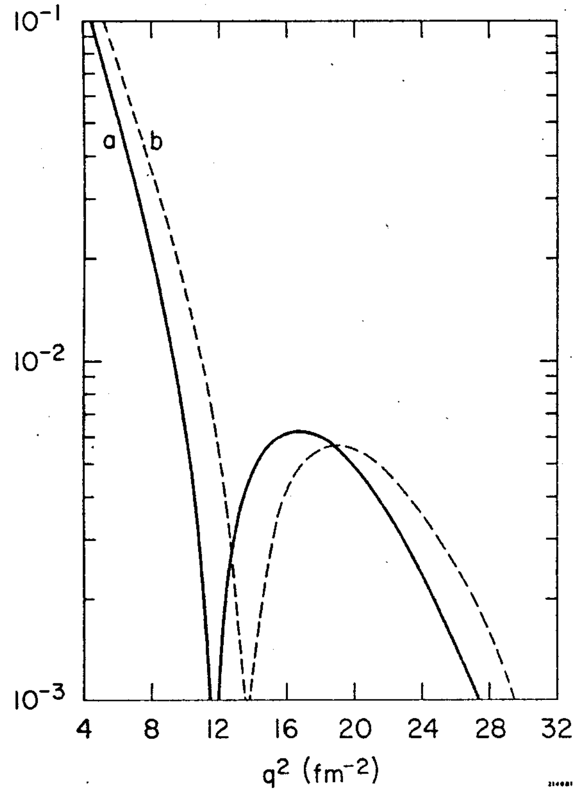

Fig. 1. Absolute value of charge form factor vs. q^2 for (a) ^3He, (b) ^3H, as given by the parametrization of Table 1.

The structure of our model is motivated by the results of numerous model calculations utilizing a hyperspherical basis.[2)] In the notation of Erens,[2)] we take

$$\psi_s(\vec{x},\vec{y}) = \phi_0^s(\rho)\, y_{00}^s(\hat{\rho}) + \phi_2^s(\rho)\, y_{20}^s(\hat{\rho}) \quad ,$$

$$\psi_{m\cdot 1}(\vec{x},\vec{y}) = \phi_1^m(\rho)\, y_{10}^{m\cdot 1}(\hat{\rho}) \;, \qquad \psi_{m\cdot 2}(\vec{x},\vec{y}) = \phi_1^m(\rho)\, y_{10}^{m\cdot 2}(\hat{\rho}) \;, \tag{3}$$

where $\rho^2 = x^2+y^2$, $d\vec{x}\, d\vec{y} = \rho^5\, d\rho\, d\hat{\rho}$. For such models, the ϕ_0^s, ϕ_2^s, ϕ_1^m components typically contribute about 97.0, 0.6, 1.6%, respectively, to the wave function norm. Using the values for $F_{ch}(^3He)$ and $F_{ch}(^3H)$ discussed above, and the proton, neutron form factors of Janssens et al.[3], eq. (1) determines F_2 and the sum F_1+F_3. These known functions were used to determine a fit for ϕ_0^s, ϕ_2^s, ϕ_1^m.

Given ϕ_0^s, ϕ_2^s, ϕ_1^m and the form of the Schrödinger equation in the hyperspherical basis, and neglecting $(\phi_2^s)^2$, $(\phi_1^m)^2$ with respect to $(\phi_0^s)^2$, it is straightforward to obtain the following expression for V_{00}, the matrix element of the potential coupling the ϕ_0^s component to itself:

$$V_{00} = -ME_0 + \left\{\phi_0^s D_0 \phi_0^s - \phi_2^s D_2 \phi_2^s - \phi_1^m D_1 \phi_1^m\right\} / \left\{2(\phi_0^s)^2\right\} \;, \tag{4}$$

where E_0 is the experimental binding energy, and

$$D_k = \frac{1}{\rho^5}\frac{d}{d\rho}\left(\rho^5 \frac{d}{d\rho}\right) - \frac{4k(k+2)}{\rho^2} \;. \tag{5}$$

Our result for V_{00} is plotted in fig. 2.

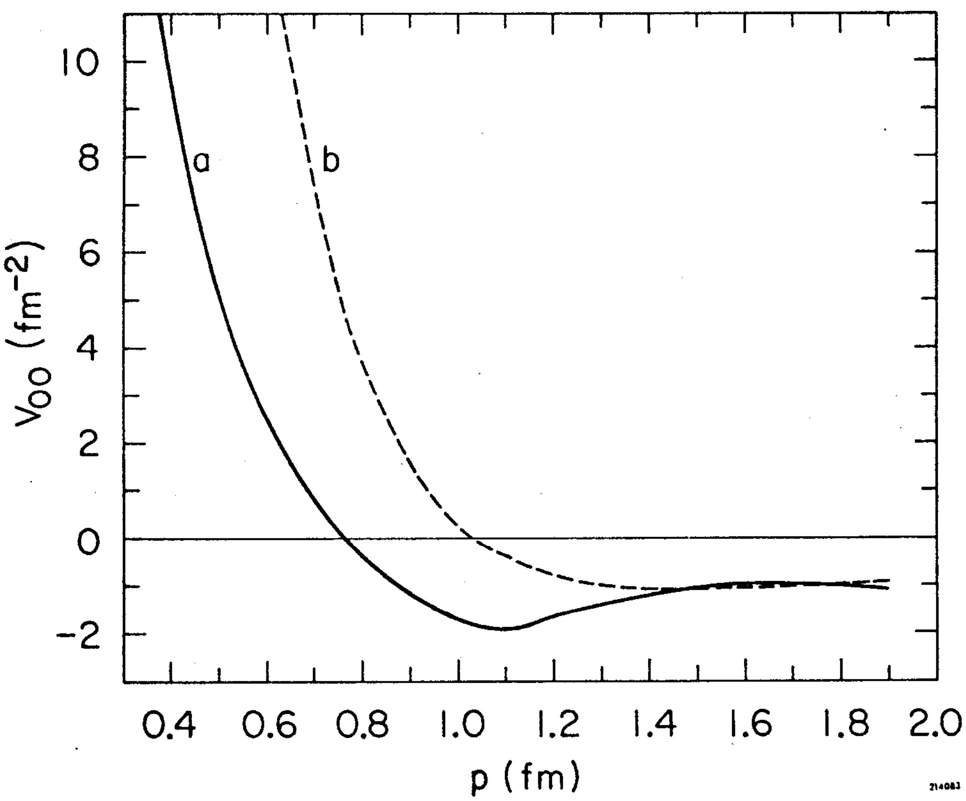

Fig. 2. The $V_{00}(\rho)$ given by our analysis for the wave function components of fig. 2 is plotted as curve (a). Curve (b) shows V_{00} as predicted by the model of Malfliet and Tjon.[4]

For comparison, we have also plotted the form of V_{00} which results from a typical nucleon-nucleon interaction model, that of Malfliet and Tjon.[4] (Our assumptions require us to consider only models in which there is no tensor force.) It seems reasonable to interpret the difference between these two curves as due to a strong attractive three-body force.

References

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