Short-range form of the charge distribution in ^{3}He

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It is shown that the short-range character of the point-proton distribution in ^{3}He cannot be determined unambiguously from experimental data, and hence it cannot serve as a basis for determining aspects of the ^{3}He structure.

[NUCLEAR STRUCTURE ^{3}He, ambiguities in charge density.]

A recent quasiexperimental result[1] showing a pronounced central depression in the *single-body*, point-proton charge distribution of ^{3}He, is contrary to theoretical predictions and hence, it has been presumed to undermine severely the credibility of theoretical models for the ^{3}He structure. The prescription used in Ref. 1 for deriving the quasiexperimental result has an appealing simplicity and has attracted the attention of many workers in the field. As a result of investigations that we have completed recently, we have come to understand that this simplicity is only apparent. We show that complications arise from both the form of the prescription and the theoretical input employed by it, and that the connection between the derived result[1] and the true ^{3}He structure is at best tenuous.

Let us recall that the observed quantities in e-^{3}He elastic scattering are the square of the charge, electric, and magnetic form factors. In contrast, the charge density $\rho(r)$ is not a direct observable but is obtained by Fourier transforming the charge form factor $F_{\rm ch}(q^2)$, e.g.,

$$\rho(r)=\frac{Z}{2\pi^2}\int dq\, q^2(\sin qr/qr)F_{\rm ch}(q^2) \ , \qquad (1)$$

where q is the momentum transfer.

Within the traditional framework of nucleons, isobars, and mesons, there are theoretical predictions for the physical charge density $\rho(r)$ (Refs. 2 and 3) which are in good agreement with the result obtained by introducing the experimental charge form factor $F_{\rm ch}^{\rm exp}(q^2)$ into Eq. (1).[4] Mesonic-exchange currents (MEC), small contributions to the single-body nuclear current (of relativistic magnitude), and the three-nucleon force, all play a role in establishing this good agreement.[2] Furthermore, the theoretical *point-proton* charge density $\rho_p(r)$ [$G_E^p=1.0$, $G_E^n=0.0$, $G_E^{p(n)}$ = proton (neutron) charge form factor] does exhibit a central depression resulting from the action of MEC contributions.[2,3] In the absence of MEC effects, there is no central depression in $\rho_p(r)$.

On the other hand, it is not at all clear how to obtain an "experimental" point-proton charge density by employing $F_{\rm ch}^{\rm exp}(q^2)$ and Eq. (1). The proton and neutron form factors enter in different combinations into the single-body (impulse approximation, IA) and MEC contributions to the ^{3}He charge form factor; hence we have no unambiguous method for unfolding the nucleon structure from the full experimental result.

It has been assumed[1] that this problem can be overcome by employing the following prescription in order to derive a quasiexperimental, "single-body," point-proton charge form factor $F_{\rm q.e.}^{\rm IA}(q^2)$

$$F_{\rm q.e.}^{\rm IA}(q^2)=(F_{\rm ch}^{\rm exp}-F_{\rm ch}^{\rm MEC})/(G_E^p+0.5G_E^n) \ , \qquad (2)$$

where $F^{\rm exp}$ is the experimental form factor and $F^{\rm MEC}$ is the theoretical MEC contribution.

The result $F_{\rm q.e.}^{\rm IA}$, introduced in turn into Eq. (1) yields a quasiexperimental quantity $\rho_{\rm q.e.}^{\rm IA}$ which may be considered to be the point-proton charge distribution in ^{3}He. This prescription would be eminently reasonable if the theoretical ingredients in Eq. (2) were known to a very good accuracy. Unfortunately, its validity is undermined by theoretical uncertainties in G_E^p, G_E^n, $F^{\rm MEC}$. It is essentially possible to produce arbitrary forms of $\rho_{\rm q.e.}^{\rm IA}$ for $r<0.8$ fm depending on the combination of models for G_E^p, G_E^n, $F^{\rm MEC}$. Thus, for example, the combination used in Ref. 1 led to a $\rho_{\rm q.e.}^{\rm IA}$ featuring a deep central depression. We argue below that this result is fortuitous.

We begin by showing in Fig. (1) the relationship between the high q behavior of model charge form factors and the short-range behavior of the corresponding $\rho(r)$ evaluated via Eq. (1) and shown in the inset. We note that a mere 20 to 30% change in the value of the form factor at the second maximum

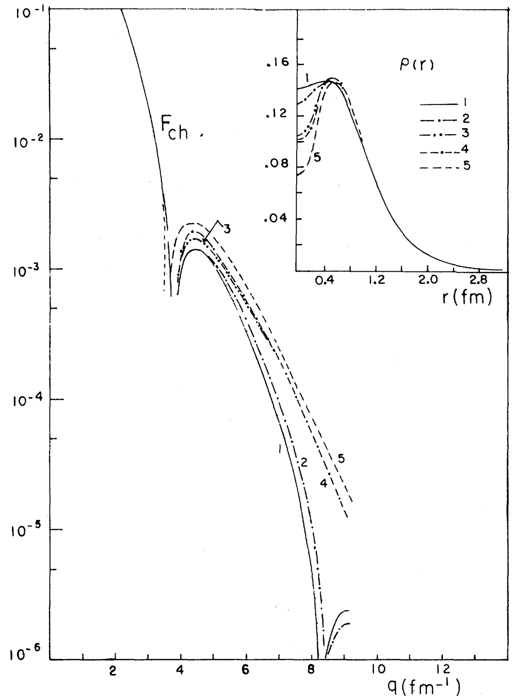

FIG. 1. Five model charge form factors. The solid line (1) is the actual theoretical impulse approximation result for ^{3}He, evaluated with the Sprung-de-Tourreil *NN* potential and the Blatnik-Zovko model for the nucleon form factors, and it incorporates the effect of a genuine three-body force. Curves 2–5 are arbitrary variations of 1. Inset: five corresponding forms of the charge density $\rho(r)$ evaluated via Eq. (1).

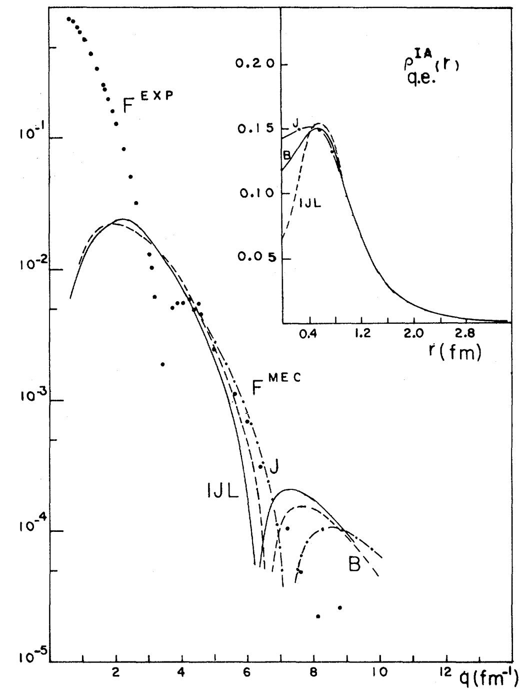

FIG. 2. Results for the MEC contribution to the charge form factor of ^{3}He, evaluated with the Blatnik-Zovko (B), Janssens (J), and IJL models for the nucleon form factors. The solid circles are experimental points (Refs. 4 and 8) shown without their error bars. Inset: three corresponding forms of $\rho^{IA}_{q.e.}$ evaluated via Eq. (1) with $F^{IA}_{q.e.}$ evaluated by means of Eq. (2).

and/or a small change in the slope at $q > 4.5$ fm^{-1} causes an essentially flat-top $\rho(r)$ (curve 1) to develop a pronounced short-range depression (curve 3 or 4). Yet, uncertainties in the theoretical ingredients F^{MEC}_{ch}, G^p_E, G^n_E, (illustrated in Fig. 2) and in the form of the prescription for $F^{IA}_{q.e.}$ are responsible for even larger variations in the form factor than those exhibited in Fig. (1). This circumstance undermines the notion that the resulting $\rho^{IA}_{q.e.}$ represents the true nature of the single-body, point-nucleon charge distribution in ^{3}He.

In particular: (1) The denominator in Eq. (2), e.g., $G^p_E+0.5G^n_E$, is only a truncated expression (appropriate for an *S*-state trinucleon system) of the correct quantity. More importantly, it introduces poorly known variables G^p_E and G^N_e for which a variety of theoretical models exist presently. The theoretical predictions of different models that we have tested,[2] begin to diverge substantially after $q \sim 5.5$ fm^{-1}. (2) The integration in Eq. (1) must be carried out to at least $q \sim 10.0$ fm^{-1} if erroneous results are to be avoided. Yet there is no reliable data out to $q \sim 10.0$ fm^{-1}; it is not clear, for example, what the phase of the last available experimental point at $q \sim 9.0$ fm^{-1} might be and whether the form factor has a second minimum at $q \sim 9$ fm^{-1} or not. From the theoretical point of view, traditional models incorporating MEC, predict that F_{ch} has a second minimum at ~ 8 fm^{-1} and a third maximum beyond this point. In contrast, dimensional-scaling quark models of ^{3}He (Ref. 5) predict a structureless behavior of F_{ch} in the region of high momentum transfer q. Without clear knowledge of F_{ch} in this region, it is not possible to determine uniquely $\rho(r)$ at short r. (3) The subtraction ($F^{exp}_{ch} - F^{MEC}_{ch}$) in Eq. (2) does not necessarily yield the true one-body (IA) result F^{IA}, since the theoretical F^{MEC}_{ch} shows several hundred percent uncertainty for $q > 6.0$ fm^{-1} due to uncertainties in *NN* models and primarily in models of the nucleon electromagnetic form factors.[2]

In Fig. 2 we present the results of our calculation of F^{MEC}_{ch} for three different models[6] of G^p_E and G^n_E (see also Fig. 1 in Ref. 2); in addition to mesonic and isobaric effects,[2] we have utilized in this work the three-body Faddeev wave functions of Grenoble which incorporate a genuine three-body force.[7] We note significant model-dependent variations in F^{MEC}_{ch} for $q > 5.0$ fm^{-1}. In view of the content of Fig. 1, these variations make it impossible to determine unambiguously the true $F^{\rm IA}$ via the subtraction indicated in Eq. (2).

Nevertheless, if we employ Eq. (2) and use the three results for $F_{\rm ch}^{\rm MEC}$ shown in Fig. 2 and the experimental data,[4,8] $F^{\rm exp}$, displayed in the same figure, we obtain $\rho_{\rm q.e}^{\rm IA}$ shown in the inset, Fig. 2. We note that the result found with the Janssens model[6] (J) has no central depression but the one with the IJL model[6] displays a pronounced short-range depression. Whatever their short-range behavior, however, it is clear that we have no basis for identifying any one of the three forms for $\rho_{\rm q.e.}^{\rm IA}$ (or any others) with the true $\rho^{\rm IA}$. After all, the three nucleon models, J, B, and IJL[6] are all reasonably consistent with available nucleon data. Hence, we cannot derive firm conclusions on ^{3}He structure by invoking the short-range behavior of $\rho_{\rm q.e.}^{\rm IA}$.

In any case, we should reiterate the view[9] that the point-nucleon charge-density of ^{3}He, being not a direct observable, should not command undue attention in investigations of the $A = 3$ nuclei. On the basis of their impact on our theoretical ideas,[2] it is the electromagnetic form factors that must be of most serious concern and must be the focus of our investigations presently.

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