Comment on the need to introduce a $T = 1$ quasideuteron

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Population of certain states seen in recent high-resolution photoproton spectra of ^{12}C, ^{16}O, and ^{40}Ca at photon energies between 61 and 77 MeV was taken as evidence for photoabsorption by $T=1$ proton-neutron pairs. This Comment suggests that the results might be more simply explained by the presence of admixed ground states in these nuclei.

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A recent paper by Van Hoorebeke *et al.* [1] reports a high-resolution measurement of the photoproton cross sections of ^{16}O, ^{12}C, and ^{40}Ca, using tagged photons with an energy of 61.0 MeV; the spectrum from the ^{12}C(γ,p) reaction was also measured at 71.0 MeV. The resolution was sufficient to resolve protons populating several low-lying states in the residual nuclei.

In the case of the ^{16}O(γ,p) reaction, there is significant population of the doublet of positive-parity states, $\frac{5}{2}^+$ at 5.27 MeV and $\frac{1}{2}^+$ at 5.30 MeV in ^{15}N (predominantly 1p-2h states), as well as the expected population of the ground ($\frac{1}{2}^-$) and third excited states at 6.32 MeV ($\frac{3}{2}^-$). We have recently measured the ^{16}O (γ,p) cross section at 46 MeV, using the tagged photon facility at Tohoku University, and confirmed population of the same low-lying states in ^{15}N. The present data are shown in Fig. 1.

The paper by Van Hoorebeke *et al.* points out that although the observed population of the ground states of the residual nuclei, and those states that have predominant single-hole configurations, is consistent with predictions of the modified quasideuteron model (QDM) of Schoch [2], population of states with largely 1p-2h configurations is not. Since these states are only weakly populated in $(e,e'p)$ experiments [3–5] which involve, in essence, a single-particle knockout mechanism, the authors concluded that the population of these states does not involve a single-particle knockout process. They proposed that the population of these states can be explained if the incident photon is absorbed by correlated proton-neutron pairs with $S=0$, $T=1$, as distinct from the coupling of $T=0$, $S=1$ in the normal QDM.

For the case of the ^{16}O(γ,p) reaction, such a mechanism would lead to population of the positive-parity doublet. This reaction process is consistent with the observation that the dominant configuration of these ^{15}N states is an *s-d* particle coupled to the 2-hole, 0^+ state in ^{14}N with $T=1$ at 2.31 MeV. The ground state and third excited state of ^{15}N, the population of which can be explained by the standard QDM, have a configuration that is dominated by a single particle coupled to the 1^+, $T=0$ ground state of ^{14}N.

The purpose of this Comment is to point out that such a modification of the QDM is not necessary to explain the population of these 1p-2h states in ^{15}N, nor the corresponding states following photoproton emission from ^{12}C and ^{40}Ca. The same residual states that are observed in Ref. [1] were seen in deexcitation γ-ray studies in the giant dipole resonance (GDR) of these same nuclei [6–10]. Their population was taken by these authors as evidence for an admixed ground state, and the collective nature of the reaction mechanism in the energy region of the GDR could explain emission from the 2p-2h components. Most of the measurements of Van Hoorebeke *et al.* were made at 66 MeV [one spectrum from the ^{12}C(γ,p) reaction was made at 77.3 MeV], at which energy the collective effects of the GDR are still present, as indicated by

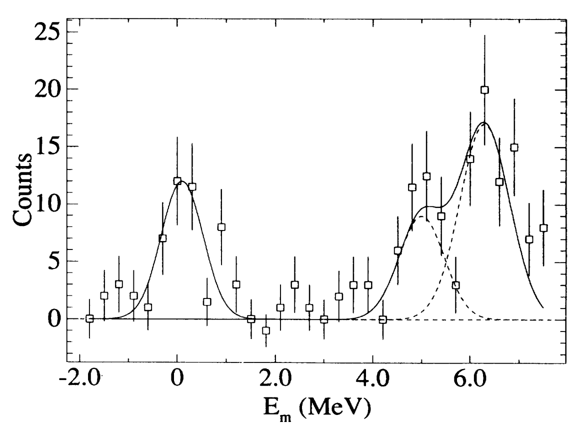

FIG. 1. Missing-energy spectrum of protons following the ^{16}O(γ,p) reaction. The data are the sum of data from five tagged-photon channels ranging from 42.6 to 50.2 MeV.

the total absorption measurements of Ahrens *et al.* [11]. It is thus likely that the same mechanism used to explain population of these 1p-2h states seen in deexcitation γ-ray measurements in the GDR region may explain the data of Ref. [1].

Although the ground-state wave function of ^{16}O consists largely of a closed neutron and proton configuration, there are significant admixtures of basis states with two or four particles in the *s*-*d* shell. Agassi *et al.* [12], in an RPA calculation, give a closed core configuration probability of 66.5%, with 2p-2h and 4p-4h components with probabilities of 27.1% and 5.5%, respectively. With such a ground-state configuration, single-proton excitation and emission can lead to population of all the states in ^{15}N that are reported in Ref. [1].

Evidence of the importance of the ^{16}O ground-state admixtures in determining which states in ^{15}N are populated following the ^{16}O(γ,p) reaction was reported many years ago by Caldwell *et al.* [6]. These measurements detected γ rays from residual states in ^{15}N following the ^{16}O(γ,p) reaction in the GDR region. Both the results of Caldwell *et al.* and those of other authors [7,8] show significant population of the positive-parity doublet in ^{15}N, and the generally accepted explanation was in terms of the ground-state admixtures in ^{16}O.

It is significant that the relative population of the $\frac{3}{2}^-$ 6.33 MeV state and the 5.27 and 5.30 MeV positive-parity doublet in ^{15}N derived from the results of Caldwell *et al.* is essentially the same as that deduced from the recent measurements of Van Hoorebeke *et al.* These ratios are shown in Table I. The similarity of this ratio over the energy range to 61 MeV suggests that the same reaction mechanism may be involved.

The results in Ref. [1] for the ^{12}C(γ,p) reaction taken at excitation energies around 61 and 77.5 MeV both show significant population of the ground states and several low-lying states in ^{11}B. Some of these states have 1p-2h structure; particularly the 6.74 MeV $\frac{7}{2}^-$, 6.79 MeV $\frac{1}{2}^+$, and 7.29 MeV $\frac{5}{2}^+$ states. The latter two states that have parentage from 2-hole, $T=1$ states in ^{10}B cannot be populated by the quasideuteron reaction mechanism. Van Hoorebeke *et al.* explain the population of most of the ^{11}B states, including that at 6.74 MeV, in terms of the modified QDM of Schoch; however, population of the positive-energy states in this model requires photoabsorption by a $T=1$ *n*-*p* pair.

TABLE I. Ratio of population of positive-parity doublets to the 6.33-MeV state in ^{15}N.

Excitation energy (MeV)	Ratio
21.0[a]	0.4±0.1
23.0[a]	0.4±0.1
25.0[a]	0.4±0.1
27.0[a]	0.3±0.1
46.3[b]	0.5±0.2
61.0[c]	0.35±0.05

[a]Reference [6].
[b]Present data.
[c]Reference [1].

The population of all the observed states can be adequately explained purely on the basis of the admixed ground state of ^{12}C. Agassi *et al.* [12] predict a ground-state wave function consisting of 43.6% closed core with 2p-2h and 4p-4h probabilities of 36.4% and 15.2%. Thus, population of the $\frac{1}{2}^+$ state at 6.79 MeV and the $\frac{5}{2}^+$ state at 7.29 MeV, which are both predominantly 1p-2h states with parentage to a $T=1$ state in ^{10}B, can occur via single-proton excitation and emission.

Even though the resolution of the data of Van Hoorebeke *et al.* is insufficient to separate the proton groups to the ^{11}B states at 6.74, 6.79, and 7.29 MeV, it is clear that there is significant population of the $\frac{5}{2}^+$ state at 7.29 MeV. A study of the deexcitation γ rays from ^{11}B following the photodisintegration of ^{12}C by Medicus *et al.* [9] also shows evidence of population of several low-lying ^{11}B states, including the $\frac{5}{2}^+$ state at 7.29 MeV. Medicus *et al.* were able to resolve all of the low-lying states, so it is necessary to compare the population of the unresolved states at 6.74, 6.79, and 7.30 MeV reported by Van Hoorebeke *et al.* with the sum of the population of these states as reported by Medicus *et al.* [9]. The ratio of the population of these states to that of the first excited state at 2.12 MeV, which is an undisputed 1-hole state that is clearly resolved in both data sets, can be calculated. From the data of Medicus *et al.*, at excitation energies between 27 and 42 MeV, it has a value ranging from 0.3 to 0.4 (with an uncertainty of about ±0.1). Although the value of this ratio from the data of Van Hoorebeke *et al.* is greater (of order 1), this may not, in view of the experimental resolution of the ^{12}C(γ,p) data of Ref. [1], provide sufficient evidence to justify the introduction of the $T=1$ quasideuteron reaction mechanism. Population of all the observed states in ^{11}B can result from admixtures in the ground state of ^{12}C.

A similar situation exists with the data from Van Hoorebeke *et al.* for the ^{40}Ca(γ,p) reaction. Although the resolution is not sufficient to separate the proton groups, there is clearly population of the first-excited state at 2.53 MeV ($\frac{1}{2}^+$) and the two negative-parity states at 2.81 ($\frac{7}{2}^-$) and 3.01 MeV ($\frac{3}{2}^-$). These latter two states have predominant 1p-2h configurations and parentage to the first $T=1$ state in ^{38}K; their population cannot be accounted for by the modified QDM, and Van Hoorebeke *et al.* invoke the $T=1$ quasideuteron to account for the data.

As for the cases of ^{16}O and ^{12}C, this is unnecessary. The ground state of ^{40}Ca has 2p-2h and 4p-4h admixtures. Agassi *et al.* [12] indicate a closed shell configuration of only 33.1%, with 2p-2h and 4p-4h contributions of 36.6% and 20.2%, respectively. Such a ground-state configuration can account for population of all of the observed states in ^{39}K, as was concluded by Ullrich *et al.* [10], who saw population of these same states in their study of deexcitation γ rays following the photodisintegration of ^{40}Ca.

This Comment is not intended to postulate or justify a particular reaction mechanism. Rather it is to indicate that the results of Van Hoorebeke *et al.* at 66 MeV are consistent with earlier data in the GDR, and are interpretable in terms of ground-state admixtures. In this regard it is probably significant that the data of Van Hoorebeke *et al.* for the $^{12}C(\gamma,p)$ taken at 77.3 MeV indicates an increasing relative population of the positive-parity state at 7.3 MeV; evidence of a reaction mechanism different from the modified QDM of Schoch, which cannot explain the population of this and similar states. It is likely that the true explanation will require a detailed microscopic calculation that incorporates, amongst other things, long-range correlations.

A measurement of the $^{16}O(\gamma,pn)^{15}N$ reaction, with sufficient resolution to determine the population of the low-lying residual states in ^{15}N, particularly the $T=1$ state at 2.31 MeV to which the 1p-2h states populated following the $^{16}O(\gamma,p)$ reaction have parentage, might clarify the dominant reaction mechanism.

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