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

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We reply to the preceding Comment.

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In a previous paper [1], we presented high resolution (γ,p) data for ^{16}O and ^{40}Ca at a mean photon energy of 61.0 MeV, and for ^{12}C at 61.0 and 77.3 MeV. The proton detection angle was fixed at 90° with respect to the photon beam. From our interpretation of the measured particle spectra, we concluded that the observed population of some excited states in the respective residual nuclei can be taken as evidence for a reaction mechanism where the incoming photon interacts with a nucleon-nucleon pair in the relative $T=1$ state. The authors of the preceding Comment present a possible alternative reaction mechanism that could be at work at the lower end of the present energy range.

When discussing the results of Ref. [1], it is important to realize that in the (γ,p) reaction (at least) three classes of states are observed to be populated. These are the 1h states and two groups of 1p-2h states that have parentage to 2h states with $T=0$ and $T=1$, respectively. The 1h states with respect to the target ground state, which includes the residual nucleus ground state, can obviously be populated via a direct knock-out (DKO) mechanism, where the photon interacts with a single proton. It has, however, been argued for a long time [2] that such transitions may also obtain a sizeable contribution from reaction mechanisms wherein the photon interacts with a proton-neutron pair in the target nucleus. In the course of such reaction, only the proton gets emitted to the continuum, while the neutron merely absorbs recoil momentum. This is the picture underlying the modified quasideuteron (MQD) model of Schoch [2]. On the basis of our data we do not claim to find evidence for the dominance of either mechanism in the population of these 1h states. It rather is our aim to help establish an extended data set which should serve as a benchmark to test various theoretical models.

In the MQD description of the transitions to 1h states, the neutron remains in its original single-particle orbit, whereas in the usual quasideuteron (γ,pn) reaction, both nucleons share the available energy on a roughly equal basis. In between these two extremes, there is the possibility for the neutron to take up only a small fraction of the photon energy, so that it changes its single-particle orbit but stays within the nucleus. This constitutes a natural reaction mechanism for the excitation of 1p-2h states in the (γ,p) reaction. Depending on the character of the *NN* pair which absorbs the incoming photon, the 1p-2h states will have strong parentage to $T=0$ ("normal" quasideuteron absorption) or $T=1$ states in the $A-2$ nucleus. Excitation of the former states was already discussed in the case of ^{12}C [3], and the purpose of our paper was to point out that we observe also excitation of the latter states. Such observation had not been made before. Given the fact that these states are relatively strongly populated, we postulated a reaction mechanism with absorption on a $T=1$ *NN* pair.

Several alternative reaction mechanisms could conceivably lead to population of the states discussed here (i.e., the positive-parity states in ^{11}B and ^{15}N, and the negative-parity states in ^{39}K). In Ref. [1] we briefly discussed the possibility of two-step processes. Such processes should, however, also populate the $\frac{5}{2}^-$ state at 4.45 MeV in ^{11}B, a transition which is not observed in our experiment. The presence of ground-state correlations can indeed lead to the excitation of 1p-2h states via a DKO reaction mechanism, since they will acquire a certain 1h component with regard to the correlated target ground state. However, the importance of these correlations in a DKO reaction can be judged from the high resolution $(e,e'p)$ experiments [4–6]. Since the $(e,e'p)$ reaction primarily proceeds via a DKO process, it yields direct information on the single-particle contents of the various states in the residual nucleus. This information is perhaps of more direct relevance in the present context than the theoretical calculations cited by Sims *et al.*, since it includes not only the effect of ground-state correlations in the target, but also the distribution of single-hole strength over the states that are of interest to us. For these states it was already pointed out in Ref. [1] that the transition strength in the (γ,p) reaction is relatively much stronger than in the case of the $(e,e'p)$ reaction. This rules out a major role for the ground-state correlations in the population of these states via a DKO mechanism. This conclusion is further corroborated by recent DKO and two-step calculations by van der Steenhoven and Blok [7] for the ^{12}C(γ,p) reaction.

Sims *et al.* seem to suggest that the role of ground-state correlations may be enhanced considerably if the reaction proceeds in a semidirect way, through intermediate excitation of the giant dipole resonance (GDR). The data on deexcitation γ-ray experiments cited by Sims

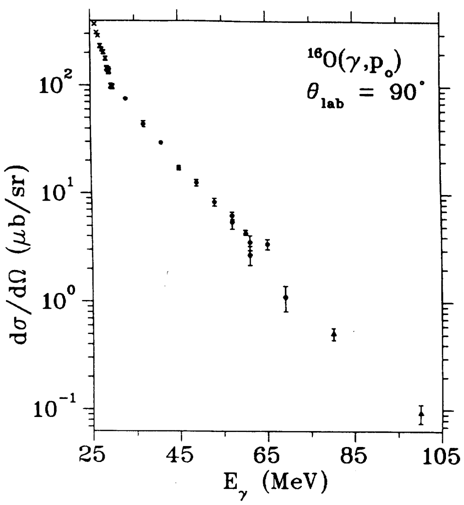

FIG. 1. The 90° differential $^{16}O(\gamma,p_0)^{15}N$ cross section. Crosses: Ref. [10]; triangles: Ref. [11]; circles: Ref. [12].

et al. indeed support such a mechanism in the energy region below 30 MeV. The relevance of these data to the present energy region is, however, disputable. The role of the GDR in the (γ,p_i) reactions decreases drastically in going from 30 to 60 MeV excitation energy. This is exemplified in Fig. 1, where we show the differential $^{16}O(\gamma,p_0)$ reaction cross section at 90° as it was recently obtained at Gent State University. It is obvious from this figure that there is a definite change in slope in the energy dependence of the cross section at around 33 MeV. This observation strongly indicates that new reaction mechanisms begin to take over above this energy. Another point of interest is the fact that Medicus *et al.* [8] observe excitation of the $\frac{5}{2}^-$ state at 4.45 MeV in ^{11}B with a strength at least comparable to the summed strength of the (in our experiment unresolved) $\frac{7}{2}^-$, $\frac{1}{2}^+$, and $\frac{5}{2}^+$ states at 6.74, 6.79, and 7.29 MeV, respectively. This stands in direct contrast to the situation observed at 61.0 and 77.3 MeV where the $\frac{5}{2}^-$ state is not observed at all (see also Ref. [8]). We also want to point out that the ratio of the unresolved 7 MeV peak in ^{11}B to the $\frac{1}{2}^-$ first excited state at a proton emission angle of 90° in our spectra is of the order of 2 to 3 (rather than 1 as claimed by Sims *et al.*), as compared to the angle-integrated values of 0.3 to 0.4 given by Medicus *et al.* [8].

Finally, in Fig. 2 we show the 90° differential cross sections for the $^{12}C(\gamma,p_i)$ reactions leading to the $\frac{3}{2}^-$ ground state, the $\frac{1}{2}^-$ (2.12 MeV) state, and the sum of the $\frac{7}{2}^-$, $\frac{1}{2}^+$, and $\frac{5}{2}^+$ states in ^{11}B. (These cross sections were obtained from the experiment in Ref. [1].) It is clear that whereas the first two channels display a strictly similar energy dependence, this is not so for the transitions to the unresolved states. Whatever reaction mechanism is responsible for the excitation of these states, it obviously becomes relatively more important with increasing photon energy, i.e., going away from the GDR. As such, it is seen to be specific to the quasideuteron energy region,

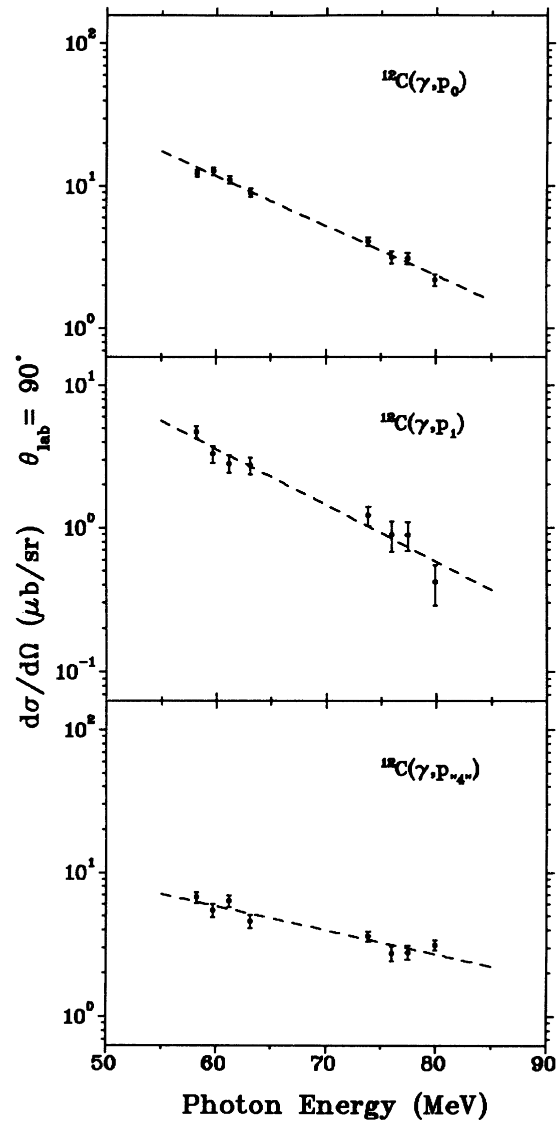

FIG. 2. The 90° differential $^{12}C(\gamma,p_i)$ cross sections for excitation of several states in ^{11}B. Upper part: ground state; middle part: $\frac{1}{2}^-$ state at 2.12 MeV; lower part: $\frac{7}{2}^-$, $\frac{1}{2}^+$, and $\frac{5}{2}^+$ states at 6.74, 6.79, and 7.29 MeV (unresolved). The dashed lines represent a fit to the data.

rather than being a phenomenon associated with the high-energy tail of the GDR.

The reaction mechanism whereby the incoming photon interacts with a *NN* pair in a relative $T=1$ state seems thus the most plausible one. Its importance can indeed be further evidenced by the study of (γ,pn) reactions with an energy resolution sufficient to separate the decay to $T=0$ and $T=1$ states in the $A-2$ nucleus. As the authors of the preceding Comment rightly point out, the precise role of the various mechanisms responsible for the absorption of intermediate-energy photons can only be clarified by further experimental work and detailed theoretical calculations.

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