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Reply to "Comment on 'Evidence for superdeformed shape isomeric states in ^{28}Si at excitations above 40 MeV through observations of selective particle decays of ^{16}O + ^{12}C resonances in ^{8}Be and alpha channels'"

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Our recent study of the ^{12}C(^{16}O,^{8}Be)^{20}Ne and ^{12}C(^{16}O,α)^{24}Mg reactions has led to the identification of two superdeformed shape isomeric states in ^{28}Si at excitation energies of 43.7 and 46.2 MeV. We conjectured from this study that these resonances have structures which correspond to the secondary minimum with deformation parameters $\epsilon=1.35$ and $\gamma=60°$ according to Nilsson-Strutinsky calculations. We give arguments to show that this conjecture is more appropriate and consistent with the presently available evidence.

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We recently reported in Ref. [1] (to be referred to hereafter as I) the identification of two intermediate structure resonances in ^{28}Si at excitation energies of $E_x=43.7$ and 46.2 MeV. In this work we measured decays to various states of the final nuclei in the reactions ^{12}C(^{16}O,^{8}Be)^{20}Ne and ^{12}C(^{16}O,α)^{24}Mg in the energy range $E_{\rm c.m.}=25.7-38.6$ MeV. The angular distribution for ^{12}C(^{16}O,α)^{24}Mg$_{\rm g.s.}$ at $E_{\rm c.m.}=26.9$ MeV allowed an assignment of the spin-parity $J^{\pi}=14^{+}$ to the $E_x=43.7$ MeV resonance.

The $E_x=43.7$ MeV resonance decays preferentially to the 0^{+} (7.20 MeV) and 4^{+}(9.04 MeV) stages of ^{20}Ne, and to the 20.2 and 21.4 MeV states of ^{24}Mg. The $E_x=46.2$ MeV resonance is also observed to decay to the 0^{+}(7.20 MeV) state of ^{20}Ne and to the 20.2 MeV state of ^{24}Mg. Combining these decay preferences with the experimental studies of the 0_3 band in ^{20}Ne made by Middleton *et al.* [2] and by Hindi *et al.* [3], we conjectured that the two ^{28}Si resonances observed in our experiment have structures which correspond to the secondary minimum with deformation parameters $\epsilon=1.35$ and $\gamma=60°$ in the potential energy surface mapped out in the Nilsson-Strutinsky(NS) calculations of Leander and Larsson for ^{28}Si [4]. We have also drawn attention to the studies by Voit *et al.* [5] and by Fulton *et al.* [6] of the near Coulomb barrier ^{12}C+^{12}C resonances in ^{24}Mg. In the Comment on our work by Zhang, Merchant, and Rae, they propose an alternative explanation of our data—based on cranked cluster model calculations [7] and on the experimental studies of the ^{12}C(^{12}C,$\alpha\alpha$)^{16}O reactions [8] of ^{12}C+^{12}C scattering [6,9] and of the ^{12}C(^{20}Ne, ^{12}C^{12}C)^{8}Be transfer reaction [10].

Their alternative explanation is mainly based on their two viewpoints. Their first viewpoint is that the band built on the 0^{+} 7.2 MeV state of ^{20}Ne is based on the ground-state ^{16}O+α configuration.

Their second viewpoint is that the 20.2 MeV state of ^{24}Mg strongly fed from the decay of the two resonances in ^{28}Si in our work [I] is the same as the 20.25 MeV state of ^{24}Mg which is observed as near barrier ^{12}C+^{12}C resonance [5].

We do not agree with both of the above viewpoints since the presently available experimental evidence are not consistent with them as explained below.

The experimental evidence from the studies of Middleton *et al.* [2] on ^{12}C(^{12}C,α)^{20}Ne clearly brings out that the 7.2 MeV, 0^{+} and 7.83, 2^{+} states are fed strongly in the reaction compared to ground-state band. From this they conclude that the ground-state is of ^{16}O+α character while 7.2 MeV, 0^{+} state is of ^{12}C+2α character. This view is also supported by the smaller alpha decay width of 7.2 MeV, 0^{+} state, than for the adjacent 6.72 MeV, 0^{+} state. In fact 7.2 MeV, 0^{+} and 7.83 MeV, 2^{+} states are weakly populated in alpha transfer reactions and strongly populated in 2α transfer while the ground-state band of ^{20}Ne is strongly populated in alpha transfer reactions [2]. The 7.2 MeV state is also populated strongly in ^{8}Be transfer on ^{12}C in the reaction ^{12}C(^{9}Be,n)^{20}Ne [11].

In addition, even in our present work [I] the resonances at 43.7 and 46.2 MeV in ^{28}Si decay to the 7.2 MeV state of ^{20}Ne and not to the ground state of ^{20}Ne even though purely from penetrability considerations, decay to ground state of ^{20}Ne will be favored. Hence all available experimental evidence support the view that 7.2 MeV, 0^{+} state of ^{20}Ne is of ^{12}C+2α character and not of ^{16}O+α character as the ground state of ^{20}Ne. Hence the possibilities of it being bandhead of 8p-4h $K^{\pi}=0^{+}$ rotational band [3] is well supported by experimental observations. The 12.44 MeV, 0^{+} state of ^{20}Ne may also be of 8p-4h character as pointed out by Zhang, Merchant, and Rae. This state had enough energy to decay to 4p-4h ^{16}O(6.05 MeV)+α while the 7.2 MeV, 0^{+} state which do not have enough energy to decay to the ^{16}O(6.05 MeV) state, shows its character to be different from ^{16}O+α by having much smaller alpha decay width of (4 keV) compared to 19 keV for the adjacent 6.72 MeV, 0^{+} state of ^{20}Ne [2] for decay to the ground state of ^{16}O.

Owing to these arguments we associate the 7.2 MeV, 0^{+} state of ^{12}C+2α character with the $(0p)^{-4}(sd)^{8}$ configuration having deformation parameters of $\epsilon=1.17$ and $\gamma=50°$ according to the Nilsson-Strutinsky calculation for ^{20}Ne [4].

Coming to their second viewpoint at the outset we wish to point out that there is no experimental evidence to associate the 20.2 MeV state strongly fed from the decay of the two resonances in ^{28}Si in our work [I] with the near Coulomb barrier $^{12}C+^{12}C$ resonance observed at 20.25 MeV [5]. In fact in our recent alpha-alpha coincidence studies [12] on $^{12}C(^{16}O,\alpha)^{24}Mg\rightarrow\alpha+^{20}Ne$ at the 43.7 MeV resonance, the measurements indicate that spins of the 20.2 and 21.4 MeV states of ^{24}Mg strongly fed at this resonance are in the region of 8 to 12 and not 4 to 6 expected [6] for $^{12}C+^{12}C$ resonances in this region. These states at 20.2 and 21.4 MeV were also found to decay preferentially to 7.2 MeV, 0^+ state of ^{20}Ne rather than to the ground state of ^{20}Ne [12].

Zhang, Merchant, and Rae assumed without definite evidence that the 20.2 MeV state of ^{24}Mg fed strongly in our work is the same as the 20.25 MeV near Coulomb barrier resonance in $^{12}C+^{12}C$ system known in literature for a long time as in the studies of Voit *et al.* [5]. Based on this assumption they further refer to the other experimental studies connected with $^{12}C+^{12}C$ resonance structures referred in Refs. [8–10]. They also associate the band built on the 20.25 MeV, $^{12}C+^{12}C$ resonance state of ^{24}Mg with the $D1$ band of the alpha cluster model based on the calculation of Marsh and Rae [7]. This corresponds to the secondary minimum at $\epsilon=1.0$, $\epsilon_3=0.3$, and $\gamma=0°$ in the potential energy surface of the NS calculations of Leander and Larsson for ^{24}Mg [4]. We argue that the 20.2 and 21.4 MeV states of ^{24}Mg strongly fed in our work [I] from the 43.7 and 46.2 MeV resonances in ^{28}Si may not be associated with the $^{12}C+^{12}C$ resonance states. We associate these 20.2 and 21.4 MeV states of ^{24}Mg with the $E1$ band of alpha cluster model with $^{12}C+3\alpha$ structure based on the same calculations of Marsh and Rae [7]. This band corresponds to $\epsilon=1.2$, $\gamma=60°$ in the potential energy surface of the NS calculations of Leander and Larsson [4] of ^{24}Mg, with the configurations of $(0p)^{-4}(sd)^{12}$. These states are fed from the resonances at 43.7 and 46.2 MeV in ^{28}Si which decay also to the 7.2 MeV, 0^+ state of ^{20}Ne (which is discussed earlier to have $^{12}C+2\alpha$ character) by ^{8}Be emission. Hence our association of these states of ^{24}Mg with the $E1$ band of $^{12}C+3\alpha$ structure is consistent with these decay modes, consequently, we associate the two ^{28}Si resonances under discussion with the potential energy minimum at $\epsilon=1.35$ and $\gamma=60°$ in NS calculations of Leander and Larsson [4]. According to these calculations, the configurations expected at this minimum is of 16p-4h character with $(0p)^{-4}(sd)^{12}(fp)^4$. This may correspond to $^{12}C+4\alpha$ configurations, but alpha cluster model calculations relating to these configurations are not available at present for ^{28}Si.

Hence we summarize that our assignment of $\epsilon=1.35$ and $\gamma=60°$ oblate structure to the two resonances observed in our work [I] is consistent with all the presently available evidence.

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