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COMMENTS

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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A recent study of the ^{12}C(^{16}O,^{8}Be)^{20}Ne and ^{12}C(^{16}O,α)^{24}Mg reactions has led, through cross channel correlation analysis, to the identification of two superdeformed shape isomeric states in ^{28}Si at excitation energies of 43.7 and 46.2 MeV. We suggest that both these states may have α-α-^{16}O-α nuclear molecule structure. Our suggestion is supported theoretically by cranked cluster model calculations and experimentally by previous studies of the ^{12}C(^{12}C,$\alpha\alpha$)^{16}O reaction, ^{12}C+^{12}C scattering, and the ^{12}C(^{20}Ne,^{12}C^{12} C)^{8}Be transfer reaction.

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Recently Eswaran *et al.* [1] have reported the discovery of two intermediate structure resonances in ^{28}Si at excitation energies of $E_x = 43.7$ and 46.2 MeV. They have 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 $E_{\text{c.m.}} = 25.7-38.6$ MeV. Their angular distribution for ^{12}C(^{16}O,α)^{24}Mg$_{\text{g.s.}}$ at $E_{\text{c.m.}} = 26.9$ MeV allows them to assign the spin-parity $J^\pi = 14^+$ to the $E_x = 43.7$ MeV resonance. However, the spin-parity of the $E_x = 46.2$ MeV resonance could not be unambiguously assigned because of its relatively small cross section for decay to any of the 0^+ states of ^{20}Ne.

The $E_x = 43.7$ MeV resonance decays preferentially to the 0^+(7.20 MeV) and 4^+(9.04 MeV) states 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. Eswaran *et al* [1] combine 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] and with the studies of the near Coulomb barrier ^{12}C+^{12}C resonances in ^{24}Mg made by Voit *et al.* [4] and by Fulton *et al.* [5]. They then conjecture that the two ^{28}Si resonances observed in their 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 [6]. In this Comment we propose an alternative explanation of their data—an explanation which is supported theoretically by cranked cluster model calculations [7] and experimentally by studies of the ^{12}C(^{12}C,$\alpha\alpha$)^{16}O reactions [8], of ^{12}C+^{12}C scattering [5,9], and of the ^{12}C(^{20}Ne,^{12}C^{12}C)^{8}Be transfer reaction [10].

The 0^+(7.20 MeV), 2^+(7.83 MeV), and 4^+(9.04 MeV) states of ^{20}Ne have long been identified as the first three members of an eight-particle–four-hole (8p4h) $K^\pi = 0_3^+$ rotational band [3]. Nevertheless, we believe that the states of this band should not be identified with the $(0p)^{-4}(sd)^8$ configuration having $\epsilon = 1.17$ and $\gamma = 50°$ of the NS calculations for ^{20}Ne [6].[1] The 8p4h description has a certain convenience but is a little ambiguous since there are many possible 8p4h states. We believe that the state is composed of a $4\hbar\omega$ collective vibration coupled to the ground state of ^{20}Ne. Since the ^{20}Ne ground state itself has an ^{16}O+α structure, the 0^+(7.20 MeV) state also has an ^{16}O+α structure. It is in this sense of the coupling of a 4p (i.e., α cluster) underlying structure to a $4\hbar\omega$ vibration that the notation 8p4h is appropriate. We suggest that the aforementioned secondary minimum in the NS potential energy surface for ^{20}Ne having $\epsilon = 1.17$ and $\gamma = 50°$, corresponding to a coplanar arrangement of alpha particles in the Bloch-Brink cluster model, should

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[1] The notation used in the literature for the relevant states of ^{20}Ne is a little confusing. The $(0p)^{-4}(sd)^8$ configuration quoted in the NS calculation has the structure $[000]^4[100]^4[010]^4[110]^4[200]^4$ (where the notation $[n_x n_y n_z]$ has its usual harmonic oscillator model meaning).

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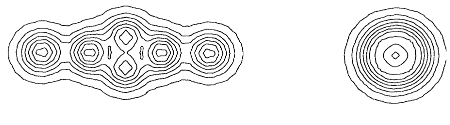
(y, or z=0) (x=0)

FIG. 1. Density profile contours for the 4:1 configuration in ^{28}Si from the Bloch-Brink alpha cluster model

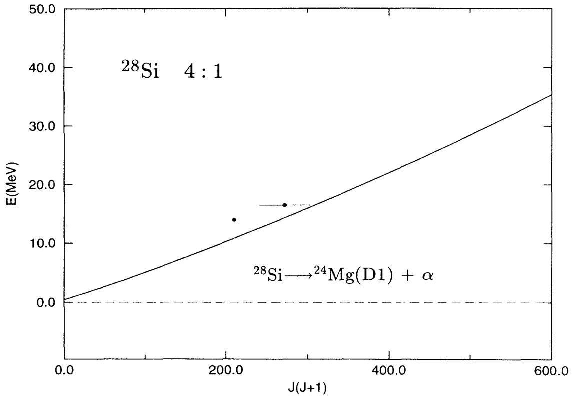

FIG. 2. Excitation energy for the 4:1 deformed states in ^{28}Si as a function of $J(J+1)$ from the cranked cluster model. Excitation energies are given relative to the $\alpha+{}^{24}$Mg($D1$ bandhead) threshold, and for the purposes of display this value is taken as zero both experimentally and theoretically. The two experimental resonances ($E_x=43.7$ MeV with $J^{\pi}=14^+$ and $E_a=46.2$ MeV which we have assumed to have $J=16\pm1$ for purposes of illustration) are also indicated by solid circles. Only results for cranking about the z axis are shown because the principal moments of inertia with respect to the y and z axes are equal (and much greater than that about the x axis).

rather be identified with the 0^+(12.44 MeV) state of ^{20}Ne [11]. The principal reason for this assertion is that the 0^+(12.44 MeV) state of ^{20}Ne decays very strongly into ^{16}O(6.05 MeV)$+\alpha$, despite its energy being only 1.62 MeV above the threshold for this channel. The 0^+(6.05 MeV) state of ^{16}O is well established as a 4p4h excitation and corresponds to the *kite* configuration in an alpha cluster model description of ^{16}O [12]. One other member of the rotational band built on the 0^+(12.44 MeV) state of ^{20}Ne is known; the 8^+(18.54 MeV) state seen in the ^{12}C(^{12}C,α)^{20}Ne reaction [8].

The 20.2 MeV state in ^{24}Mg is one of the resonances seen in the ^{12}C(^{12}C,α)^{20}Ne reaction by Voit *et al.* [4]. It decays selectively through the ^{20}Ne$+\alpha$ channel and preferentially populates the quartet of states 0^+(6.72 MeV), 0^+(7.20 MeV), 2^+(7.43 MeV), and 2^+(7.84 MeV) in ^{20}Ne. This indicates that the 20.2 MeV state in ^{24}Mg may have an α-^{16}O-α structure. More recently, in a study of the ^{12}C(^{20}Ne,^{12}C^{12}C)^{8}Be reaction Fulton *et al.* [10] observed a series of discrete narrow resonances at high excitation energies in ^{24}Mg which appear to correlate with those previously observed in ^{12}C$+{}^{12}$C scattering. Clearly, the states of ^{24}Mg populated in the ^{12}C(^{20}Ne,^{12}C^{12}C)^{8}Be reaction should have an α-^{16}O-α structure. We believe that they correspond 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 [6]. They would thus be associated with the $D1$ band of ^{24}Mg, as predicted by cranked Hartree-Fock calculations [13] and Bloch-Brink alpha cluster model calculations [7]. The $D1$ band calculated in the alpha cluster model is predicted [7] to have many of the properties of the resonances in ^{24}Mg beginning at 20.2 MeV excitation.

In view of our assertion that the band built on the 0^+(7.20 MeV) state of ^{20}Ne is based on the ground state ^{16}O$+\alpha$ configuration, and the band built on the 20.2 MeV state of ^{24}Mg is the $D1$ band of the alpha cluster model, we associate the two structure resonances seen by Eswaran *et al.* [1] with the mass-asymmetric secondary minimum ($\epsilon=1.0$, $\epsilon_3=0.3$, and $\gamma=0^0$) in the potential energy surface of the NS calculations of Leander and Larsson for ^{28}Si [6]. This minimum is related to an α-α-^{16}O-α cluster configuration predicted by the alpha cluster model (the results of which we present below) and by the deformed harmonic oscillator model.

Our calculated density profile contours of the α-α-^{16}O-α configuration are shown in Fig. 1, and the corresponding geometric positions of the alpha cluster centers are listed in Table I. The NS calculation of Leander and Larsson for ^{28}Si [6] gave only the static configuration (i.e., 0^+ bandhead). We have performed cranked alpha cluster model calculations [14] for this configuration. Figure 2 shows the rotational energy of the band in ^{28}Si plotted as a function of $J(J+1)$. The band terminates at $J=30\hbar$.

In order to be consistent with previous calculations of this kind we use the Brink-Boeker B1 force for the nucleon-nucleon interaction in our calculations. As already noted previously [7,15], the B1 force does not predict the absolute values of binding energies in agreement with experiment. However, if a band head has a well-defined fission or separation channel we can compare theoretical and experimental values of E_b-E_s for the most appropriate channel, where E_b is the binding energy

TABLE I. Geometric arrangement of alpha cluster centers for the 4:1 configuration of ^{28}Si.

Cluster position	R_1 (fm)	R_2 (fm)	R_3 (fm)	R_4 (fm)	R_5 (fm)	R_6 (fm)	R_7 (fm)
x	−6.45	−2.63	0.00	0.00	0.00	2.63	6.45
y	0.00	0.00	−0.95	−0.25	1.20	0.00	0.00
z	0.00	0.00	−0.83	1.24	−0.41	0.00	0.00

for the bandhead and E_s is the sum of binding energies for the fragments. The comparison made in this way is usually more reasonable than that obtained from a direct comparison of the calculated excitation energy with that of the ground state or with some other arbitrary bandhead. As mentioned above no J^π value could be assigned to the $E_x = 46.2$ MeV resonance, and so our comparison of binding energies has been restricted to the $E_x = 43.7$ MeV resonance which has $J^\pi = 14^+$. The graph of Fig. 2 shows the predicted energies and experimental data.

To summarize, we have presented an alternative interpretation of the resonances recently observed in the reactions $^{12}C(^{16}O,^{8}Be)^{20}Ne$ and $^{12}C(^{16}O,\alpha)^{24}Mg$. Although we must admit that the experimental data so far accummulated for these resonances are not adequate for us to draw absolutely firm conclusions, we believe that our interpretation is more consistent with the known properties of the states populated in ^{20}Ne and ^{24}Mg.

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