Structure of the $^{12}C + ^{12}C$ resonances

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(Received 20 November 1975)

It is shown that the resonances in the $^{12}C + ^{12}C$ system near and below the Coulomb barrier can be understood in the framework of the quasimolecular model. The model accounts for all the observed resonances without introducing new degrees of freedom.

[NUCLEAR STRUCTURE $^{12}C + ^{12}C$ resonances calculated, J, π. Quasimolecular model.]

Since the discoveries in the $^{12}C + ^{12}C$ system of resonances at energies near[1] and below[2] the Coulomb barrier, a lot of theoretical work has been carried out in order to explain them. In 1968 Imanishi[3] proposed a model in which the resonances are interpreted as quasimolecular states arising from the interaction between the two ^{12}C nuclei, one in the ground state and the other in the first excited 2^+ state. This calculation quite satisfactorily reproduced the three resonances known at the time, namely, the ones at 5.6 MeV (2^+), 6.0 MeV (4^+), and the third at 6.3 MeV. For the last resonance a spin $J = 0^+$ was predicted. In 1972 Michaud and Vogt,[4] based on the discovery of more resonances below the Coulomb barrier,[2] objected to the quasimolecular model on the grounds that it was unable to account for all the resonances observed. Using qualitative arguments they propose that the resonances are due to an intermediate structure based on an α-particle model.

It is the purpose of this note to show that there is no need to introduce more degrees of freedom, since actually *all* resonances are accounted for in the quasimolecular model. All one has to do is slightly modify Imanishi's choice of parameters in order to account for the new sub-Coulomb resonance data, unknown to him at the time. In Imanishi's calculation, the depth of the $^{12}C - ^{12}C$ potential was fixed to obtain the first rotational $L = 2$ degenerate triplet ($J = 0^+, 2^+, 4^+$) in the energy region of the three resonances known then. It should be noted that the spins $J = 2^+$ and $J = 4^+$ agree well with the assignments of Almqvist *et al.*[1] However, their data rule out $J = 0^+$ for the third resonance. In fact they suggest $J > 4^+$ for the resonance at 6.3 MeV, predicted by Imanishi to have $J = 0^+$.

All these arguments, together with the fact that

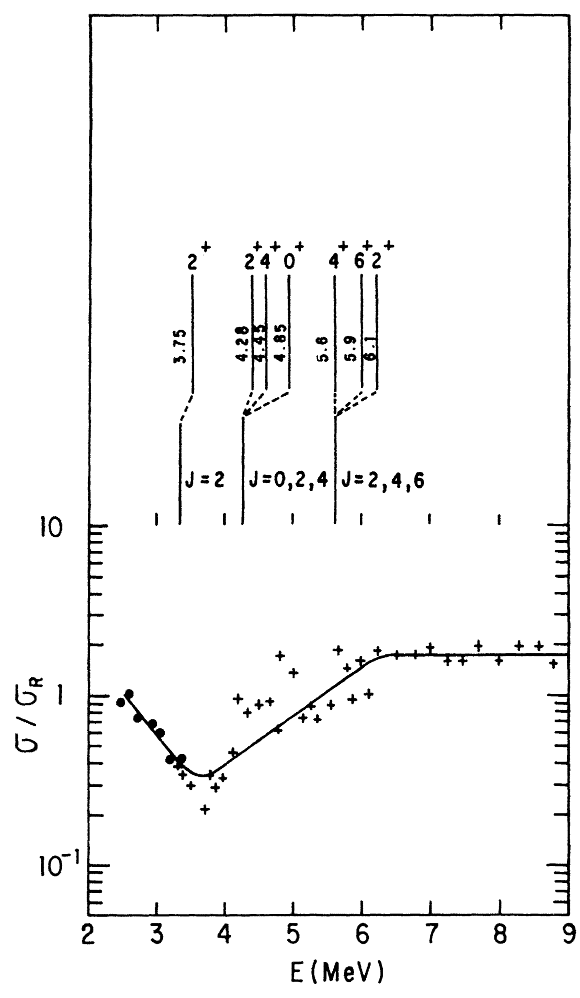

FIG. 1. Experimental total cross section showing the resonances and their calculated energies and spins.

the quasimolecular model actually predicts seven states rather than three, whereas between six and eight resonances are experimentally observed, suggest the following modifications. Looking at Imanishi's spectrum,[5] we see that in order to fit the experimental data it has to be somewhat compressed and lowered by about 1 MeV. The later is achieved by modifying the potential depth by roughly that amount. It turns out that compressing the spectrum is not difficult. Since the relative motion of the two ^{12}C nuclei is treated as "rotator-like", it simply depends on the value used for the inertia parameter $R = \hbar^2/2\mu\langle r^2\rangle$.

Imanishi uses an estimated value of $R = 0.15$ MeV. If R is made smaller the rotational spectrum is compressed. For instance, using $R = 0.1$ MeV and a potential 1 MeV shallower, one obtains the results shown in Fig. 1 (instead of Imanishi's case 2-b). As can be seen, the agreement is quite impressive. It does not seem necessary to invoke extra degrees of freedom in order to understand the sub-Couloumb resonances of $^{12}C + ^{12}C$. The quasimolecular model seems quite adequate. In this version, the highest resonances at 5.6, 6.0, and 6.3 MeV correspond to the $L = 4$ triplet, rather than to the $L = 2$ one.

The spins predicted in this case are $J = 2^+$, 4^+, and 6^+, consistent with the experimental data.[1] Moreover, another four resonances are predicted between 3.5 MeV and 5.0 MeV with spins $J = 0^+$, 2^+, 4^+ (the first triplet), and 2^+. They should correspond to the sub-Coulomb resonances[2] found below 5 MeV.

This description hinges on the value used for the inertia parameter, and therefore we have calculated it. For Imanishi's case 2 (shallow potential) and $L = 4$ we find $R = 0.115$ MeV. The 1 MeV increase in the potential depth should make this if anything smaller, bringing it closer to the value of 0.1 used here.

In conclusion the quasimolecular model accounts for *all* observed resonances, and there seems to be no need to introduce new degrees of freedom.

We thank R. Stock for drawing our attention to this problem.

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[1]E. Almqvist, D. A. Bromley, J. A. Kuehner, and B. Whalen, Phys. Rev. 130, 1140 (1963).

[2]M. G. Mazarakis and W. E. Stephens, Phys. Rev. C 7, 1290 (1973).

[3]B. Imanishi, Nucl. Phys. A125, 33 (1968).

[4]G. J. Michaud and E. W. Vogt, Phys. Rev. C 5, 350 (1972).

[5]See Figs. 1 and 2 of Ref. 3.