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$J^{\pi}=6^{+}$ molecular state below the barrier of the $^{12}C+^{12}C$ system

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Angular distributions of the $^{12}C(^{12}C,\alpha_0)^{20}Ne$ reaction have been measured from $E_{c.m.}=5.2$ to 5.8 MeV in 20 keV steps. At $E_{c.m.}=5.435$ MeV a 6^{+} state is reported.

Experimental work of almost three decades has established a large number of molecular resonances in the $^{12}C+^{12}C$ system.[1] The evidence for these resonances is most distinct for states occurring in the $^{12}C+^{12}C$ barrier region since the resonance parameters (spin J, parity π, elastic partial width Γ_{el}) could be reliably determined. In spite of extensive studies, only resonance states with $J\leq 4$ have been found up to now at subbarrier energies.[2-5] The reason is that states with $J>4$ are strongly suppressed by penetrability effects, and thus very hard to detect experimentally. Recently published rotational-vibrational models of the $^{12}C+^{12}C$ system[6-11] predict, on the other hand, resonance states with $J=6$ and 8 below the barrier. In order to find out if such low-energy, high-spin resonances exist, indeed, we have reinvestigated the $^{12}C+^{12}C$ system at subbarrier energies. We find evidence for a $J^{\pi}=6^{+}$ state which is reported in this paper.

We have measured angular distributions ($\theta_{c.m.}\approx 8°-90°$ in 3.5° steps) of the reaction $^{12}C(^{12}C,\alpha_0)^{20}Ne$ in the energy range $E_{c.m.}=5.207-5.791$ MeV in steps of $\Delta E=20$ keV. The data were taken at the Erlangen EN tandem accelerator. The experimental setup was identical with that described in Refs. 12 and 13. In contrast to Refs. 12 and 13 we used, however, solid self-supporting ^{12}C targets with a thickness of 6-7.5 $\mu g/cm^2$. The targets were surrounded by a liquid-nitrogen trap and were changed frequently to keep the carbon buildup as small as possible. All energies stated in the figures and quoted in the text are given in the c.m. system and are corrected for the ^{12}C energy loss in the target.

The analysis of the $^{12}C(^{12}C,\alpha_0)^{20}Ne$ differential reaction cross-section data was performed with the computer code CRAZS[14] according to a recently developed method described in Ref. 15. The method is applicable for spin-zero particles. It yields all possible sets of equivalent solutions for the scattering matrix elements S_l from a Legendre polynomial fit of the angular distributions.

Figure 1 shows $^{12}C(^{12}C,\alpha_0)^{20}Ne$ angular distributions in the energy range of particular interest ($E_{c.m.}=5.406-5.489$ MeV) in addition with the results of Legendre polynomial fits performed with different numbers of partial waves ($l=0$, 2, 4 corresponds to the dashed, and $l=0$, 2, 4, 6 to the solid curves). In contrast to all other angular distributions measured between $E_{c.m.}=5.2$ and 5.8 MeV it is not possible to obtain a good fit if only the partial waves $l=0$, 2, and 4 are used. The $l=6$ partial wave is absolutely needed in addition in order to get agreement with the experimental data.

The moduli of the $l=6$ S-matrix elements extracted from the fit of the angular distributions of Fig. 1 are shown in Fig. 2 (lower part). They display a resonance-

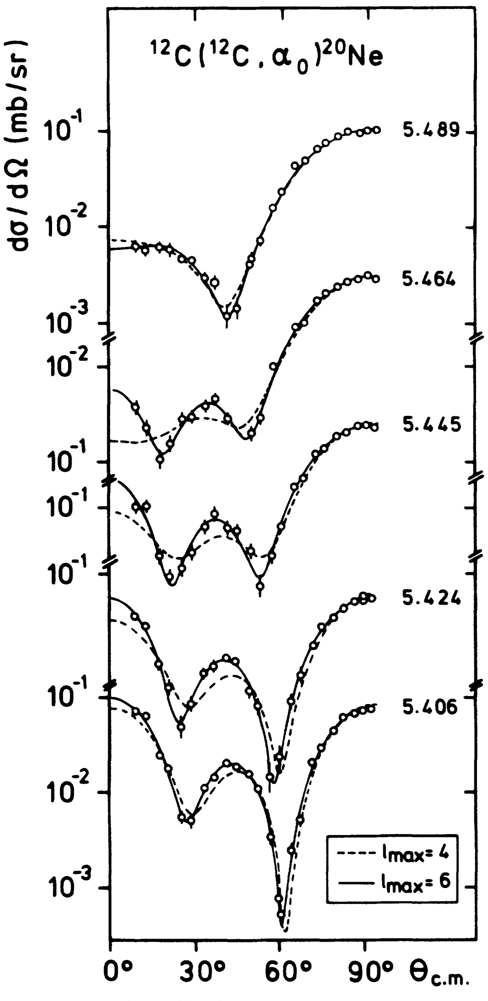

FIG. 1. Angular distributions of the reaction $^{12}C(^{12}C,\alpha_0)^{20}Ne$. The numbers at the right refer to the c.m. energies. The dashed and solid curves are the results of Legendre polynomial fits to the data performed with $l_{max}=4$ and $l_{max}=6$, respectively.

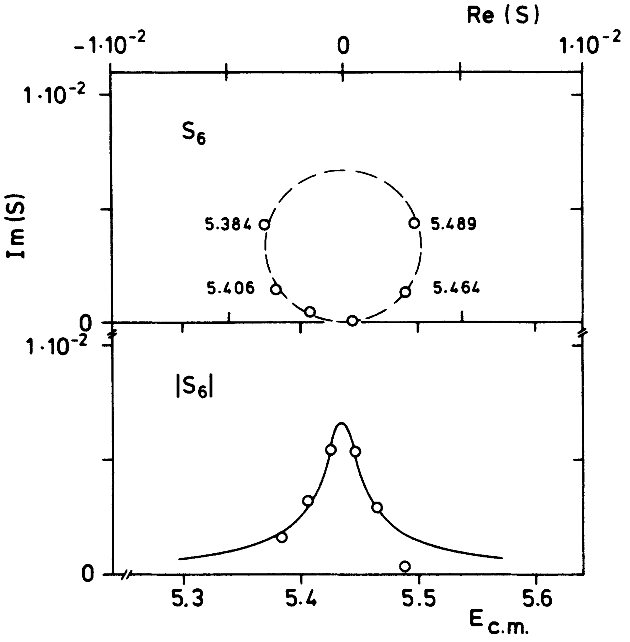

FIG. 2. Energy dependence of the moduli of S_6 extracted from a Legendre polynomial fit to the $^{12}C(^{12}C,\alpha_0)$ angular distributions measured between 5.384 and 5.489 MeV (lower part) and Argand plot for the $l=6$ S-matrix elements (upper part). The solid line in the lower part is the result of a one-level Breit-Wigner fit, the numbers in the upper part indicate the corresponding c.m. energy, the dashed curve simply connects the S_6 values.

like behavior at $E_{\text{res}}=5.435$ MeV with a width of 30 keV. The solid curve in Fig. 2 represents a Breit-Wigner fit. It should be noted that the moduli of the scattering matrix elements with the highest contributing l quantum number (i.e., $|S_6|$) are uniquely obtained from the Legendre polynomial fit.[12] In the upper part of Fig. 2, the Argand diagram for the $l=6$ scattering matrix elements is shown. It exhibits the behavior expected for a genuine resonance (remember that the overall phase of the S-matrix elements is a free parameter in an energy-independent analysis[12]). We conclude from these features of the S_6-matrix elements that a genuine $J^\pi=6^+$ resonance exists in the ^{24}Mg composite system at an excitation energy $E_x=19.365$ MeV.

It should be noted that common $^{12}C+^{12}C$ optical-model potentials yield very low transmission coefficient T_l for the $l=6$ partial wave in the energy range studied ($T_6\approx10^{-2}$–10^{-3}). The same holds for $\alpha+^{20}$Ne potentials. Thus, it is quite obvious that a $J^\pi=6^+$ state does not show up as a resonant structure in angle integrated $^{12}C(^{12}C,\alpha)$ excitation functions.

The rotational-vibrational models mentioned above predict a $J^\pi=6^+$ state at roughly that energy. In Ref. 6 a $J^\pi=6^+$ state with vibrational quantum number $v=1$ is proposed at $E_{\text{c.m.}}=5.4$ MeV, in Ref. 9 a $J^\pi=6^+$ state with $v=0$ at $E_{\text{c.m.}}=5.2$ MeV. The $J^\pi=6^+$ resonance state found in this work could possibly correspond to this predicted state. It is obvious, however, that the additional low-energy, high-spin states predicted by these models have to be confirmed experimentally before such a conclusion can be finally drawn.

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