Resonant behaviour in the interaction of the $^{12}\text{C} + ^{12}\text{C}$ system at energies above the coulomb barrier

Z. Basrak, F. Auger, B. Fernandez, J. Gastebois, N. Cindro

► To cite this version:

Z. Basrak, F. Auger, B. Fernandez, J. Gastebois, N. Cindro. Resonant behaviour in the interaction of the $^{12}\text{C} + ^{12}\text{C}$ system at energies above the coulomb barrier. *Journal de Physique Lettres*, 1976, 37 (6), pp.131-134. 10.1051/jphyslet:01976003706013100 . jpa-00231256

HAL Id: jpa-00231256

<https://hal.science/jpa-00231256>

Submitted on 1 Jan 1976

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification
 Physics Abstracts
 4.310 — 4.375

RESONANT BEHAVIOUR IN THE INTERACTION OF THE $^{12}\text{C} + ^{12}\text{C}$ SYSTEM AT ENERGIES ABOVE THE COULOMB BARRIER

Z. BASRAK

Institut « Rudjer-Boskovic », Zagreb, Yugoslavia
 and Département de Physique Nucléaire, C.E.N. Saclay, B.P. 2,
 91190 Gif-sur-Yvette, France

F. AUGER, B. FERNANDEZ, J. GASTEBOIS

Département de Physique Nucléaire, C.E.N. Saclay, B.P. 2,
 91190 Gif-sur-Yvette, France

and

N. CINDRO (*)

Service de Physique Nucléaire, C.E.N. Bruyères-le-Châtel,
 92120 Montrouge, France

(Reçu le 27 janvier 1976, révisé le 17 mars 1976, accepté le 6 avril 1976)

Résumé. — Des résonances ont été observées dans l'interaction $^{12}\text{C} + ^{12}\text{C}$ aux énergies $E_{\text{cm}} = 7,45, 8,45, 8,85$ et $9,25$ MeV qui correspondent aux énergies d'excitation de ^{24}Mg de 21,4, 22,4, 22,8 et 23,2 MeV respectivement. Ces résonances sont visibles dans les voies de sortie proton et particules alpha. Dans cette région d'énergie, des résonances dans le système $^{12}\text{C} + ^{12}\text{C}$ n'avaient pas encore été observées alors que des calculs théoriques prévoyaient l'existence d'un groupe de résonances autour de $E_{\text{cm}} = 7,6$ MeV.

Abstract. — Resonances in the $^{12}\text{C} + ^{12}\text{C}$ interaction at $E_{\text{cm}} = 7.45, 8.45, 8.85$ and 9.25 MeV corresponding to excitation energies in ^{24}Mg of 21.4, 22.4, 22.8 and 23.2 MeV respectively are reported. These resonances are seen in the proton and alpha exit channels. No resonances in $^{12}\text{C} + ^{12}\text{C}$ were reported previously in this energy region, where earlier calculations predicted a group around $E_{\text{cm}} = 7.6$ MeV.

Since the discovery fifteen years ago [1] of the three resonances in $^{12}\text{C} + ^{12}\text{C}$ near $E_{\text{cm}} = 6$ MeV, the resonant behaviour of this system was the object of frequent experimental and theoretical studies. The major obstacle in understanding this behaviour was the inability of the phenomenological models to reproduce the increasing number of resonances discovered around the Coulomb barrier region. Recently, however; Park, Scheid and Greiner [2] and Kondo, Matsuse and Abe [3] have succeeded in removing this difficulty by an appropriate choice of scattering potentials. The latter authors together with qualitatively accounting for the existing resonances, have, moreover, predicted a group of resonances ($8^+, 4^+, 6^+$) centered around

$$E_{\text{cm}} = 7.6 \text{ MeV } [E_x \{ ^{24}\text{Mg} \} = 21.5 \text{ MeV}]$$

where none were previously observed. A more careful scrutiny of existing data, however, could have indicated the presence of resonance behaviour around 7.5 MeV (cm) : a minimum in the $^{12}\text{C} + ^{12}\text{C}$ elastic scattering excitation function at 90° near that energy was reported in reference [4]. Also, several strong peaks in the excitation function of the inverse $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction were observed in reference [5] for excitation energies in ^{24}Mg corresponding to center of mass energies of the $^{12}\text{C} + ^{12}\text{C}$ system in the above region. Thus a detailed study of the resonant behaviour of $^{12}\text{C} + ^{12}\text{C}$ in this energy region appeared to be quite interesting.

We have measured the excitation functions of the reactions $^{12}\text{C}(^{12}\text{C}, p)^{23}\text{Na}$ at 15° lab. and $^{12}\text{C}(^{12}\text{C}, \alpha)^{20}\text{Ne}$ at 15° and 35° lab. respectively using the Saclay tandem van de Graaff accelerator. The measurements were performed in energy steps of 200 keV from $E_{\text{lab}} = 14$ to 22 MeV ($E_{\text{cm}} = 7\text{--}11$ MeV).

(*) Permanent address : Laboratory for Nuclear Spectroscopy, Institute « R. Boskovic », Zagreb, Yugoslavia.

The protons and alpha particles were detected simultaneously in two ΔE - E telescopic detectors. The overall energy resolution of the measurement was about 150 keV for protons and 180 keV for alphas; these figures include the beam energy spread (~ 130 -150 keV on a $27 \mu\text{g}/\text{cm}^2$ ^{12}C target).

The excitation functions for three proton groups ($\theta_{\text{lab}} = 15^\circ$) leading respectively to the states of ^{23}Na at 0.0, 2.08 and 3.68 MeV excitation and for four alpha groups ($\theta_{\text{lab}} = 15^\circ$ and 35° respectively), leading respectively to the states in ^{20}Ne at 0.0, 1.63, 4.25 and 4.97 MeV, are shown from top to bottom in figure 1. In addition, excitation functions were measured for twelve other proton groups leading to levels up to 6.65 MeV excitation in ^{23}Na and also for five other alpha groups leading to levels up to 7.14 MeV excitation in ^{20}Ne , but none of them are shown in the figure. Some of these levels were unresolved. Their pattern is quite similar to those shown in the figure.

FIG. 1. — Excitation functions for (top to bottom) three proton groups ($\theta_{\text{lab}} = 15^\circ$) leading to, respectively, the states of 0.0, 2.08 and 3.68 MeV excitation in ^{23}Na , for four alpha groups ($\theta_{\text{lab}} = 15^\circ$) leading to, respectively, the states of 0.0, 1.63, 4.25 and 4.97 MeV excitation in ^{20}Ne and for the same alpha groups at $\theta_{\text{lab}} = 35^\circ$. The dashed curves represent excitation functions averaged over 3 000 keV.

Resonant behaviour is quite apparent at several energies where either strong maxima or strong minima are observed in almost all excitation functions. The width of these resonances can be estimated to be about 400 keV laboratory energy. A shift in the energy of the

resonances by about 200 keV was observed in some excitation functions; we shall return to this point later on.

In order to determine which of the observed deviations (maxima and minima) from the average trend of the excitation functions are non-statistical, we have calculated for each excitation function $\sigma_{\theta,f}(E)$ leading to a final state f measured at a detecting angle θ a deviation function :

$$D_{\theta,f}(E) = \left| \frac{\sigma_{\theta,f}(E) - \overline{\sigma_{\theta,f}(E)}}{\overline{\sigma_{\theta,f}(E)}} \right|$$

where $\overline{\sigma_{\theta,f}(E)}$ is an average taken over a given energy interval centered around E . Correlated (non-statistical) deviations should persist in all or most deviation functions, thus in their sum. Several averaging intervals ($\Delta E_{\text{lab}} = 600$ to 3 000 keV) were used in computing the deviation functions; this altered the peak-to-valley ratios and caused small shifts (~ 200 keV) in the positions of the peaks, but did not alter the general pattern of the deviation functions, at least for intervals wider than about 1 000 keV.

FIG. 2. — Summed deviation functions for, respectively, (top to bottom) fifteen proton groups at 15° [$E_{\text{exc}}(^{23}\text{Na}) = 0.0, 0.44, 2.08, 2.39, 2.64 + 2.71, 2.98, 3.68, 3.85 + 3.91, 4.43, 4.78, 5.38 + 5.52, 5.78, 5.97 + 6.07, 6.25 + 6.40$ and 6.65 MeV] and for nine alpha groups at 15° and 35° [$E_{\text{exc}}(^{20}\text{Ne}) = 0.0, 1.63, 4.25, 4.97, 5.62 + 5.78, 6.72, 7.01 + 7.16, 7.42$ and 7.84 MeV] and for the whole set of results (protons and alphas, all angles). The averaging interval in this figure was of 3 000 keV. The four vertical dashed lines show the locations of reported resonances.

The summed deviation functions for 15 proton groups at 15° , for 9 alpha groups at 15° and at 35° and for the whole set of results (protons and alphas) are shown, respectively, from top to bottom in figure 2.

The partial deviation functions were computed with an averaging interval $\Delta E_{\text{lab}} = 3\,000$ keV. Peaks in the total summed deviation function (all particles) are visible at $E_{\text{lab}} = 14.9, 16.9, 17.7$ and 18.5 MeV corresponding to excitation energies in ^{24}Mg of 21.4, 22.4, 22.8 and 23.2 MeV respectively. It should be noted that only the peaks at 16.9 and 17.7 MeV show up in all the channel deviation functions (see Fig. 2).

Let us examine the resonances associated with the above peaks in more detail. As mentioned before, a strong peak was observed in the excitation function of the inverse $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction at $E_{\text{cm}} = 12.1$ MeV [5]. The excitation energy in ^{24}Mg corresponding to this peak ($E_{\text{exc}} = 21.4$ MeV) is equal to that for our peak at $E_{\text{lab}} = 14.9$ MeV (see Table I). From the experimental angular distribution it was possible to attribute the peak at 12.1 MeV to two overlapping levels having $J = 4$ and 6 respectively [5]. In the present data the $E_{\text{lab}} = 14.9$ MeV peak is visible only in the alpha particle exit channels. We have no means of establishing whether our observation stands for a single or for several closely spaced resonances. The energy shift observed in some excitation functions might indicate that at least two closely spaced resonances are present. Moreover, a peak near $E_{\text{lab}} = 15.4$ MeV [$E_{\text{ex}}(^{24}\text{Mg}) \approx 21.7$ MeV] is observed in our experiment in the proton deviation functions: resonances of different spin will indeed show up with different strengths in proton and alpha particle channels.

It is worth pointing out that other resonance peaks observed in the inverse $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction show a certain correlation with the peaks observed in the summed deviation functions of, respectively, the alpha particle and proton channels in our experiment. The comparison is shown in table I.

As to speculations about the nature of the observed resonances, it is above all tempting to associate some or the whole group of the three resonances with the levels $J = 8, 4$ and 6 predicted around 21.5 MeV in ^{24}Mg in the calculations of Kondo *et al.* [3] with the peak observed near $E_{\text{lab}} = 14.9$ MeV in our experiment and the mentioned 12.1 MeV peak in $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ both corresponding to $E_{\text{ex}} = 21.4$ MeV in ^{24}Mg (see Table I). The agreement with the above calculations would indicate a molecular character of the 21.4 MeV resonance. As the observation of the same resonance in the $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction would favour its alpha structure configuration, the combined

TABLE I

Comparison between the peaks observed in the excitation function at 90° of the $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction (ref. [5]) and the present data (deviation functions) ()*

$^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$		Present work		
$E_{\text{cm}}(\alpha)$	$E_{\text{ex}}(^{24}\text{Mg})$	$E_{\text{ex}}(^{24}\text{Mg})$	$E_{\text{cm}}(^{12}\text{C})$	$E_{\text{lab}}(^{12}\text{C})$
12.1	21.4	21.4	7.45	14.9
12.6	21.9	(21.7) 22.4	(7.7) 8.45	(15.4) 16.9
13.6	22.9	22.8	8.85	17.7
13.9	23.2	23.2	9.25	18.5

(*) Energies are uncertain up to 200 keV in the $^{20}\text{Ne} + \alpha$ experiment and up to 100 keV in the present work (cm).

results of references [3, 5] and our experiment may appear as rather puzzling. Several comments are, however, appropriate. First, the fact that the $^{12}\text{C}(^{12}\text{C}, \alpha_0)^{20}\text{Ne}$ and the $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reactions show resonant behaviour at the same energy (in ^{24}Mg) may be simply due to their inverseness. This fact then only adds to the reality of a resonance at 21.4 MeV in ^{24}Mg , but need not generate contradictory structural considerations. Furthermore, the 21.4 MeV resonance was observed in the $^{12}\text{C} + ^{12}\text{C}$ entrance channel leading to all or most of alpha exit channels and the inverse (i.e. $^{20}\text{Ne} + \alpha \rightarrow ^{12}\text{C}^* + ^{12}\text{C}^*$) not having been observed, we have more reason to believe in a resonance in the $^{12}\text{C} + ^{12}\text{C}$ entrance channel. A predominantly $^{12}\text{C} + ^{12}\text{C}$ molecular character for the resonance at 21.4 MeV in ^{24}Mg may therefore be deduced. The agreement with the calculated energy of the $J = 8, 4$ and 6 group (ref. [5]), although strengthening this point, could nevertheless be fortuitous. In fact, the weakness of the 21.4 MeV resonance in the proton exit channels (see Fig. 2) although explainable in terms of a possible high angular momentum ($J \geq 6$), points out that the presence of alpha configurations in the wave function of the 21.4 MeV resonance should not be excluded.

As to the nature of other resonances (22.4, 22.8 and 23.2 MeV in ^{24}Mg) observed in the present experiment, in view of their correlation with peaks observed in the $^{20}\text{Ne}(\alpha, ^{12}\text{C})^{12}\text{C}$ reaction, arguments similar to the above ones can be advanced about the interplay of $^{12}\text{C} + ^{12}\text{C}$ vs alpha and/or other configurations [6]. It is, however, interesting to point out that resonances of molecular character were predicted in reference [2] at excitation energies in ^{24}Mg of 22.2 (10^+), 22.8 (8^+) and 23.2 MeV (6^+) respectively, in rather good agreement with our findings.

References

- [1] ALMQUIST, E., BROMLEY, D. A. and KUEHNER, J. A., *Phys. Rev. Lett.* **4** (1960) 515.
 - [2] PARK, J. Y., SCHEID, W. and GREINER, W., *Contrib. Int. Conf. on Reactions between Complex Nuclei*, Nashville, Tenn. (1974), p. 3 and *Phys. Rev. C* **10** (1974) 967.
 - [3] KONDO, Y., MATSUSE, T. and ABE, Y., *Contrib. 2nd Int. Conf. on clustering Phenomena in Nuclei*, College Park, Md (1975), paper VII-B-5.
 - [4] SPINKA, H., Ph. D. Thesis, Calif. Inst. of Technology (1971) unpublished ;
SPINKA, H. and WINKLER, H., *Nucl. Phys. A* **233** (1974) 456.
 - [5] LASSEN, N. O. and OLSEN, J. S., *Mat. Fys. Medd. Dan. Vid. Selsk.* **33**, n° 13 (1963).
 - [6] MICHAUD, G. J. and VOGT, E. N., *Phys. Rev. C* **5** (1972) 350.
VOIT, H., ISCHENKO, G. and SILLER, F., *Phys. Rev. Lett.* **30** (1973) 564.
-