Spin assignments for the resonant structures in the $^{12}C + ^{12}C$ system through the reaction $^{12}C(^{12}C,^{16}O_{g.s.})^8Be_{g.s.}$ at $E_{c.m.} = 6$–11 MeV

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(Received 15 January 1979)

The resonant structures in the $^{12}C + ^{12}C$ system have been studied through the reaction $^{12}C(^{12}C,^{16}O_{g.s.})^8Be_{g.s.}$ at $E_{c.m.} = 6$–11 MeV. Excitation functions of the reaction have been measured in 50-keV steps at 14 angles between $\theta_{c.m.} \sim 29°$ and $\sim 90°$. Resonant structures have been found at 5.94, 6.41, 6.68, 7.47, 7.90, 8.10, 8.37, 8.58, 8.88, 9.08, 9.34, 9.56, 9.70, 9.99, 10.29, 10.43, 10.68, and 10.98 MeV. Some of these are new resonances. Their J^π values have been assigned to be 4^+(5.94 MeV), 2^+(6.41 MeV), 2^+(6.68 MeV), 4^+(7.90 MeV), $2^+ + 4^+$(8.10 MeV), 4^+(8.37 MeV), 4^+(8.58 MeV), 6^+(8.88 MeV), 6^+(9.08 MeV), 6^+(9.34 MeV), 6^+(9.56 MeV), 6^+(9.70 MeV), 6^+(9.99 MeV), (8^+)(10.29 MeV), (8^+)(10.43 MeV), 8^+(10.68 MeV), and 8^+(10.98 MeV). An interesting relation between this exit channel and the α,γ exit channels has been found. This may give us important information about the structure of the resonances. Good correspondence has been found with several levels appearing in the reaction $^{12}C(^{16}O,\alpha)^{24}Mg^*$. This fact suggests that the resonances in the ^{16}O-^8Be channel are true states of ^{24}Mg.

[NUCLEAR REACTIONS $^{12}C(^{12}C,^{16}O_{g.s.})^8Be_{g.s.}$, $E_{c.m.} = 6-11$ MeV; $\theta_{c.m.} = 29-90°$; measured $\sigma(\theta, E)$; deduced resonance energies, J^π values, total widths, partial-width products $(\Gamma_c \cdot \Gamma_0)$.]

I. INTRODUCTION

The resonant structures in the $^{12}C + ^{12}C$ system have been studied through the reaction $^{12}C(^{12}C,^{16}O_{g.s.})^8Be_{g.s.}$ from $E_{c.m.} = 6$ to 11 MeV. In this energy region several experiments have been performed through several exit channels in the system: n, p channels in Ref. 1, α channel in Refs. 1–4, γ channel in Refs. 1, 5, and 6, and the inverse α channel in Ref. 7. Several resonances have been found by these experiments in the energy region. J^π values for most of the resonances have been assigned.[1-5] In the ^{16}O-^8Be channel we have reported spin assignments for four resonances in our previous Letter.[8] Cooper *et al.* and James *et al.* have reported preliminary results only at $E_{c.m.} = 5.5-6.5$ MeV and $E_{c.m.} = 9.0-20.0$ MeV, respectively, in this channel.[9,10] Recently, Lazzarini *et al.* have found many molecularlike states in the α spectra of the reaction $^{12}C(^{16}O, \alpha)^{24}Mg^*$.[11] But correspondence between these levels and the resonances in the $^{12}C + ^{12}C$ system was rather poor in this energy region.

Theoretically, several models about these resonances have been presented; potential model,[12,13] α-doorway model,[14] nuclear-molecule model,[15,16] and band crossing model.[17] So far, theoretical investigation in this energy region has not been performed very well because of the poor experimental information of these resonances.

In this paper we report spin-parity assignments of the resonances in the $^{16}O_{g.s.}$-$^8Be_{g.s.}$ channel at $E_{c.m.} = 6$ to 11 MeV and discuss correspondence between our results and those of the other exit channels.

The $^{16}O_{g.s.}$-$^8Be_{g.s.}$ channel is favorable for the spin assignments of this system for the following reasons. The Q value of this exit channel is only 200 keV and the moment of inertia is as large as that of the $^{12}C + ^{12}C$ system; thus this channel has a good angular momentum matching for the incident channel. Moreover, as in the ^{16}O-^8Be channel only the transitions to $^8Be_{g.s.}$ and ^8Be (2^+, 2.9 MeV) are allowed below $E_{c.m.} \approx 12$ MeV: resonance effects are expected to reflect strongly in the $^{16}O_{g.s.}$-$^8Be_{g.s.}$ channel. These are in contrast with the other exit channels. As J^π values of the particles appearing in this channel are all 0^+, spin of the resonance can be simply determined from the angular distribution comparing with a square of Legendre polynomial with a single L value.

Recently, Tohsaki-Suzuki[18] suggested that the ^{16}O-^8Be configuration overlapped well with the $^{12}C_{g.s.}$-$^{12}C_{g.s.}$ one through the $^{12}C_{g.s.}$-$^{12}C^*$ (0_1^+) configuration at the contact distance. This makes us believe that we can possibly get important information about the structure of the resonances through the ^{16}O-^8Be channel.

II. EXPERIMENT AND RESULTS

The experiment has been performed by the Kyoto University tandem Van de Graaff accelerator. A broad range gas ΔE-E counter telescope was used to detect low energy recoiled ^{16}O particles, where an ionization chamber and a position

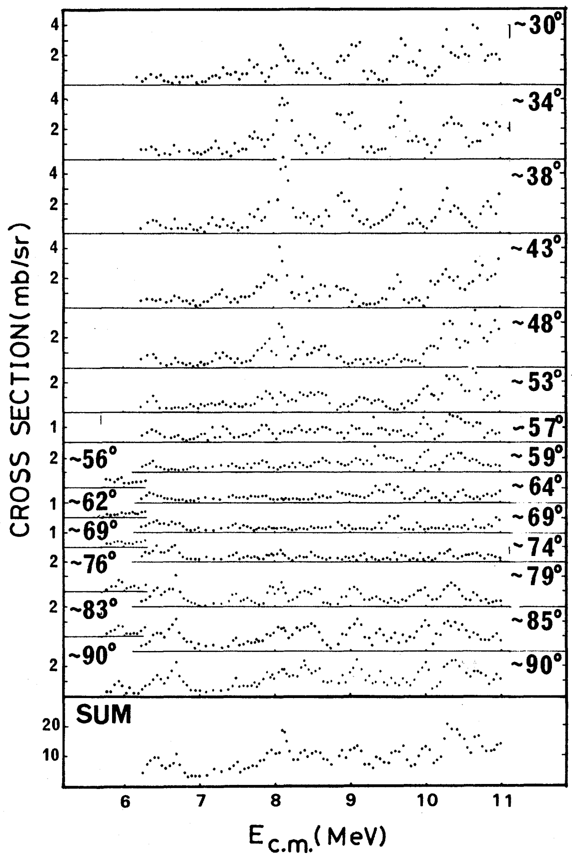

FIG. 1. Excitation functions of the reaction $^{12}C(^{12}C, {}^{16}O_{g.s.})^{8}Be_{g.s.}$. The lowest column is one summed over 14 angles. $\theta_{c.m.}$ in the figure have an ambiguity of about one degree between 6 and 11 MeV.

sensitive solid state detector (15×50 mm^2) were used as ΔE counter and E counter, respectively. By this counter system we measured the reaction simultaneously at seven angles which were defined by slits. Carbon, oxygen, and neon were clearly identified.

A thin carbon target ($6 \sim 9$ μg/cm^2) was used and the energy losses in the target were about 15–20 keV (c.m.). A liquid nitrogen trap and target heating method (~300°C) were used to suppress carbon buildup. The target has three layers, one gold layer (1 μg/cm^2) and two carbon layers.[19] The gold layer is sandwiched by two carbon layers to avoid gold evaporation. Absolute cross sections were determined by assuming that the elastic scattering of carbon by gold is pure Rutherford scattering.

Excitation functions have been measured in 50-keV steps at 14 angles from 6.2 to 11 MeV and at six angles from 5.6 to 6.2 MeV. These excitation functions are shown in Fig. 1. The lowest column shows summed cross sections, where a cross section at each angle is multiplied by $\sin\theta$ and summed.

III. RESONANCES

Several criteria have been proposed to identify resonances. Generally, the following four criteria have been used. (i) Angle-integrated excitation functions, or at least excitation functions summed over several angles, should be used. (ii) Resonance effects should appear correlated, preferably in all exit channels. (iii) If all nuclei have zero spin, the angular distribution measured at a resonance energy should exhibit a unique L value. (iv) The observed cross section should be considerably larger than those predicted by the statistical theory of nuclear reactions. In the criteria, as discussed by Taras and Voit *et al.*,[4,20] criterion (ii) is too severe (later we will show a good example of this in our system), and criteria (iii) and (iv) are insufficient. Voit *et al.*[4] have added the following fifth criterion. (v) True resonances should survive if one adds up many excitation functions from single transitions. In our case this criterion is not applied as mentioned before. Thus we identified the resonances mainly by the criterion (i) and used the correlations between the exit channels to confirm them.

Recently, three interesting experiments have been performed in this energy region. The first one is about the reaction $^{12}C(^{12}C, \alpha)^{20}Ne$ in Refs. 2 and 4. Voit *et al.* have studied this reaction in detail in the energy range between 4.0 to 12.0 MeV. They have identified the resonances in the α exit channel mainly by the criteria (i) and (v). J^π values of these have been assigned from the angular distributions by the coefficients of Legendre polynomial expansion. The results of Erb *et al.*[2] agree with these.

The second one is the reaction $^{12}C(^{12}C, \gamma_{0,1,2,3})^{24}Mg^*$ by Sandorfi *et al.*[6] They detected the high energy γ rays which were emitted in the transition directly from the "molecular state" to the ground state (0^+), first excited state (2^+, 1.37 MeV), and second and third excited states ($4^+ + 2^+$, $4.12 + 4.23$ MeV) of ^{24}Mg. They have found four remarkable resonances at $E_{c.m.} = 6$–8 MeV. The experiment shows explicitly that these resonances are true states of ^{24}Mg.

The third is the reaction $^{12}C(^{16}O, \alpha)^{24}Mg^*$ by Lazzarini *et al.*[11] They have studied the α spectra of the reaction. They have measured the reaction at $E(^{16}O) = 62$–100 MeV in 1-MeV steps and found clear peaks around E_x (^{24}Mg) ≈ 20–30 MeV in the summed spectrum after proper background was subtracted from each spectrum. If we assume that the ^{12}C transfer process in this reaction is direct, we can expect that molecularlike states with good angular momentum matching are strongly enhanced, provided that these states exist as true excited states in ^{24}Mg.

Later we will refer to the results of the above three experiments in the mention of each resonance.

A. Resonance energies and widths

Strong angle correlated structures are found at the following energies: $E_{\mathrm{c.m.}} = 5.94$, 6.41, 6.68, 7.47, 7.90, 8.10, 8.37, 8.58, 8.88, 9.08, 9.34, 9.56, 9.70, 9.99, 10.29, 10.43, 10.68, and 10.98 MeV. They survived in the summed excitation function as shown in the lowest column of Fig. 1. According to the above discussion, we identified them as resonances. The resonance energies (E_j), total widths (Γ_t), and partial-width products ($\Gamma_c \cdot \Gamma_0$) have been determined, taking into account of J^π values given in the next subsection, mainly from the summed excitation function. They have been extracted by the following formulas under the assumption that the resonances are isolated ones with a Breit-Wigner shape:

$$\frac{d\sigma}{d\Omega}(\theta) = \sum_j \frac{2\Gamma_c\Gamma_0}{(E-E_j)^2 + \Gamma_t^{\,2}/4} \times \left| C_{1j}P_{L1}(\cos\theta) + C_{2j}\exp(-i\phi_j)P_{L2}(\cos\theta)\right|^2 , \tag{1}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{SUM}} = \sum_i \frac{d\sigma}{d\Omega}(\theta_i)\sin\theta_i \, . \tag{2}$$

Here $C_{kj} = A_{kj}\lambda\!\!\!^{-}(L+\frac{1}{2})$ with ($k = 1, 2$) and ϕ_j is the relative phase. $A_{1j} \equiv 1$ and $A_{2j} = 0$ when angular distribution of the jth resonance is well reproduced with a unique L value. Otherwise, they are given in the next subsection.

The calculated results are given in Figs. 2(a)–(d). In the lowest column they are for the summed excitation function by the above formula (2) (solid curves) and by only each resonance term with each L value {dotted dash [$L = L1$ in the formula (1)] and dotted curves ($L = L2$)}. In the upper two figures they are for ones at two angles near the peaks of the Legendre polynomial by the formula (1). The extracted values are given in Table I. The resonance energies and Γ_t are estimated to be accurate within about ±30 and ±50 keV, respectively. Mean values of the partial-width product are about 10~15% of the total widths. This means that the partial widths of the ^{16}O-^{8}Be channel (Γ_0) may be as large as those of the elastic channel (Γ_c), if we assume that the latter are 10~15% of the total widths.

B. Spin-parity assignments

Angular distributions on the resonant structures and at typical off-resonance energies are shown in Fig. 3. The latter is those in Figs. 3(b), (e), (i), (n), (r), and (w). These structureless angular distributions indicate that the other on-resonance ones reflect J^π values of the resonance. They are compared with squares of Legendre polynomial with single L value (solid curves in the figure) or with two L values given by the following formula (dotted ones):

$$\frac{d\sigma}{d\Omega}(\theta) \propto \left| \, P_{L1}(\cos\theta) + A\exp(-i\phi)P_{L2}(\cos\theta)\right|^2 . \tag{3}$$

The following spin assignments have been made for these resonant structures:

5.94 MeV. The angular distribution is well fitted by $|P_4(\cos\theta)|^2$ at backward angle as shown in Fig. 3(a). This resonance appears in the γ, n, p, α, and ^{8}Be exit channels.[1,4,5,8-10] The result of $J^\pi = 4^+$ agrees with those of Refs. 1, 4, 8, and 9. The peak at 6.07 MeV in the γ channel in Ref. 6 may be different from this, because $J^\pi = 4^+$ assignment is rejected in that peak. The resonance does not also appear in the α spectrum of the reaction ^{12}C(^{16}O, α) ^{24}Mg*.[11]

6.41 MeV. The fit by $|P_2(\cos\theta)|^2$ is very well at backward angle, but poor at forward angle [Fig. 3(e)]. $L = 0$ wave mixture improves this fit. The parameter set of the formula (3) of the dotted line in the figure is ($L1 = 2$, $L2 = 0$, $A = 0.3$, $\phi = 100°$). This shows that $L = 2$ wave is dominant in the resonance. This seems to be the same one appearing at about 6.3 MeV in the other exit channels,[1,4] but their resonance energies differ by 110–160 keV. This difference may be explained by the interference effect between this and the resonance at 6.68 MeV as pointed out in our previous report.[8] This corresponds to the strong peak at $E_x(^{24}\mathrm{Mg}) \approx 20.3$ MeV in the α spectrum.[11]

6.68 MeV. The angular distribution resembles that of the 6.41 MeV resonance and well reproduced by the formula (3) by the parameter set ($L1 = 2$, $L2 = 0$, $A = 0.2$, $\phi = 120°$). $L = 2$ wave dominates in this resonance. This result agrees with that of phase shift analysis by Korotky *et al.*[5] This resonance is not observed in the α exit channel, However, in the γ channel[6] clear resonance appears at $E_{\mathrm{c.m.}} = 6.74$ MeV. $J^\pi = 2^+$ assignment is not inconsistent with the result of this reaction. This resonance corresponds to a small peak in the α spectrum[11] at $E_x(^{24}\mathrm{Mg}) \approx 20.7$ MeV.

7.47 MeV. The angular distribution is well fitted by $|P_2(\cos\theta)|^2$ at backward angle and by $|P_6(\cos\theta)|^2$ at forward angle. Basrak *et al.*[3] re-

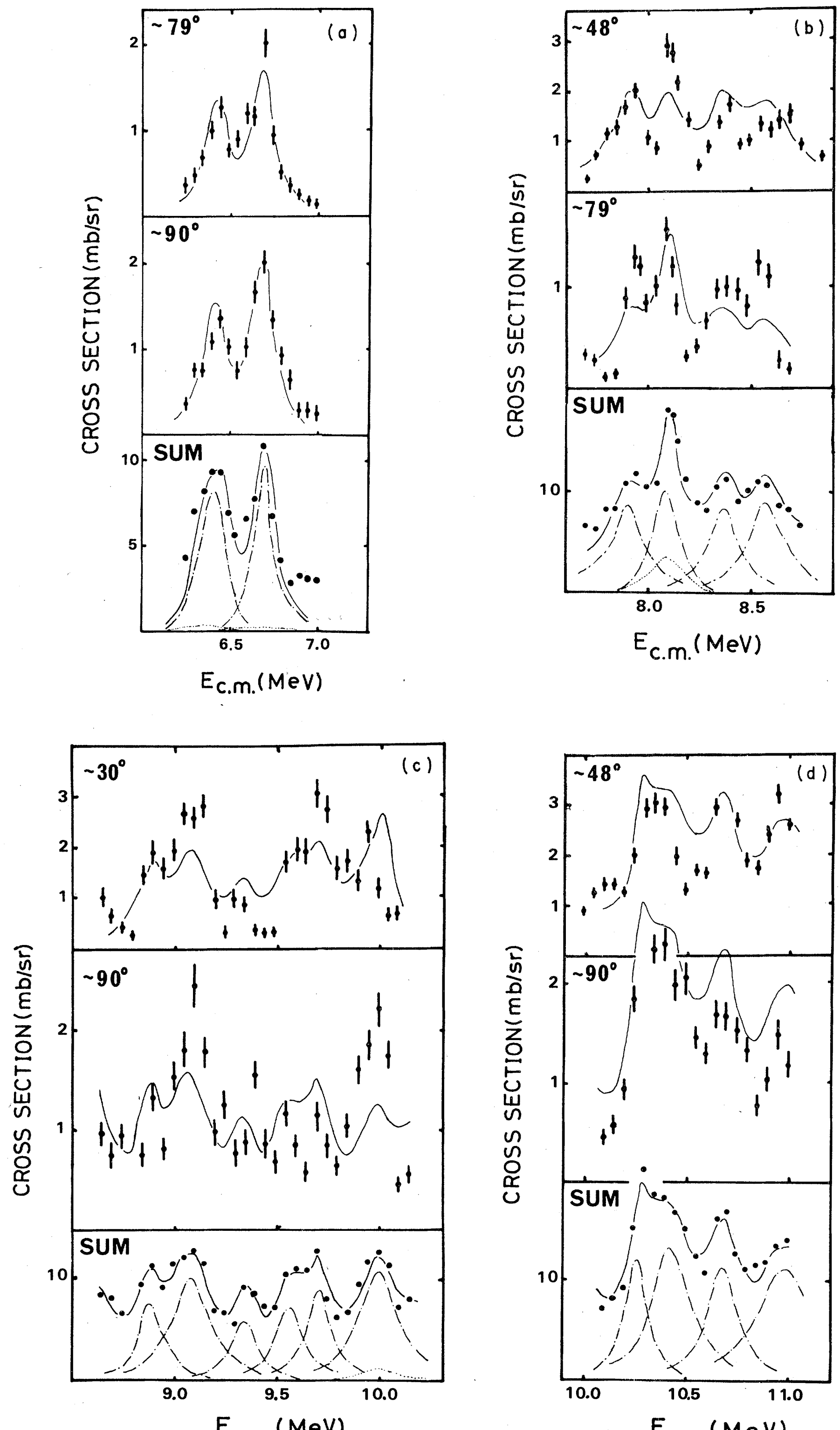

FIG. 2. The excitation functions in the region of same J^π values. The solid curves are for the results of the fits by formula (1). Dotted-dash and dotted curves are for each resonance term with $L=L1$ and $L=L2$, respectively. See the text. (a) $J^\pi=2^+$: $L1=2$ (dotted-dash curve), $L2=0$ (dotted curve). (b) $J^\pi=4^+$: $L1=4$, $L2=2$. (c) $J^\pi=6^+$: $L1=6$, $L2=4$. (d) $J^\pi=8^+$: $L1=8$.

TABLE I. Resonance energies, J^π values, total widths, mean values of the ratio of partial width to total width, and integrated cross sections of the resonances in the ^{16}O-^{8}Be channel at $E_{c.m.} = 6$ MeV–11 MeV.

E_j (c.m.) (MeV)	J^π	Γ_{total} (keV)	$\frac{(\Gamma_c \times \Gamma_0)^{1/2}}{\Gamma_t}$ (%)	σ (mb)
5.94	4^+			
6.41	2^+	140	15.8	17.4
6.68	2^+	150	16.9	18.8
7.47	?	150	11.0	12.9
7.90	4^+	200	11.0	12.1
8.10	$2^+ + 4^+$	150	12.2	20.9
8.37	4^+	150	11.2	12.0
8.58	4^+	220	11.7	12.6
8.88	6^+	150	8.3	8.9
9.08	6^+	220	10.2	12.9
9.34	6^+	150	7.6	7.1
9.56	6^+	150	8.4	8.4
9.70	6^+	150	9.5	10.7
9.99	6^+	220	10.9	14.4
10.29	(8^+)	140	10.6	16.3
10.43	(8^+)	250	11.5	18.7
10.68	8^+	180	10.8	16.4
10.98	8^+	270	11.3	17.3

ported from the analysis of the α exit channel that the peak at 7.47 MeV had $J^\pi = 6^+$. Lassen *et al.*[7] showed from the inverse α channel that $L = 4$ wave was dominant in this peak. However, Voit *et al.*[4] and Erb *et al.*[2] have identified no resonance near 7.5 MeV. Their excitation functions show that this energy corresponds to a large minimum. A strong peak appears in the γ channel.[6] $J^\pi = 4^+$ is preferable from this data and 6^+ is excluded, but 2^+ is not. At this stage we cannot determine J^π values of the structure. A large peak is found in the α spectrum in Ref. 11 at corresponding energy $E_x(^{24}Mg) \approx 21.4$ MeV.

7.90, 8.37, 8.58 MeV. These three angular distributions are very well reproduced by $|P_4(\cos\theta)|^2$. Each J^π value of the resonances is 4^+. These three resonances appear in the α exit channel and the J^π values agree with those of this channel.[4] In the α spectrum[11] the 7.90 MeV resonance corresponds to a small peak near and below the larger one at $E_x(^{24}Mg) \approx 22.0$ MeV. The peaks corresponding to the other two resonances are not clearly seen.

8.10 MeV. The peak and valley of this angular distribution are shifted largely to forward angle

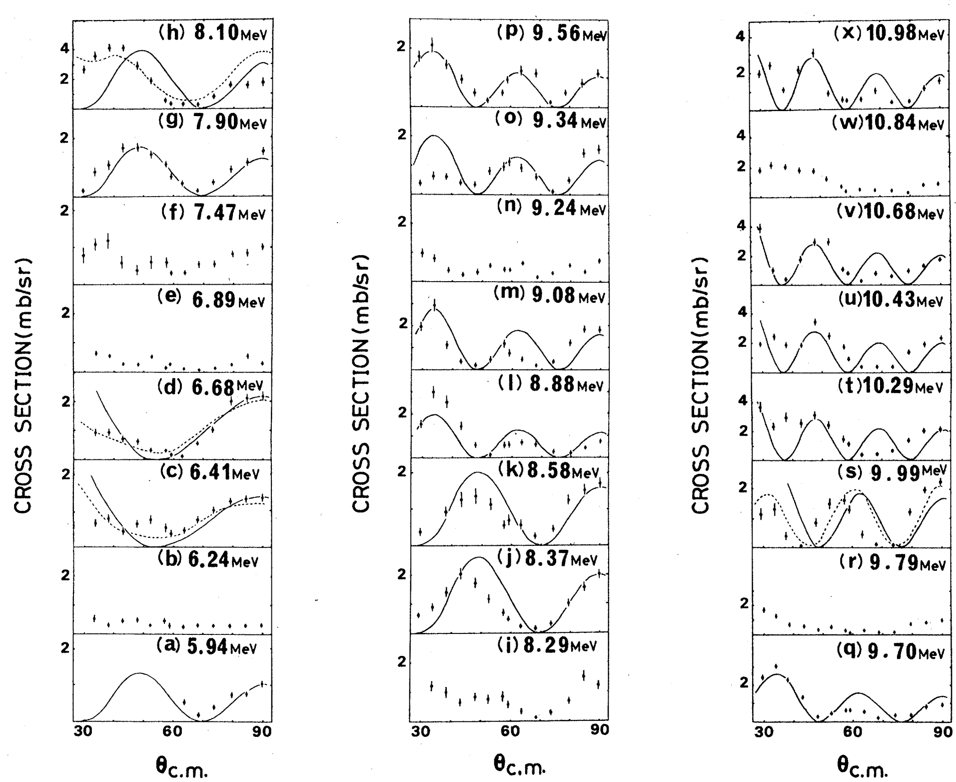

FIG. 3. Angular distributions on and off the resonances. Off-resonance ones are Figs. (b), (e), (i), (n), (r), and (w). Solid curves are by $C|P_2(\cos\theta)|^2$ (C:const). About L values, see the text. Dotted line are explained in the text.

from $|P_4(\cos\theta)|^2$ [Fig. 3(h)]. The mixture of $L=2$ wave with about the same amplitude of $L=4$ wave makes the fit better. The parameter set is ($L1=2$, $L2=4$, $A=1.1$, $\phi=100°$). We may say that this resonance is a doublet with $J^\pi=2^+$ and 4^+. This doublet is not observed in the α channel,[2,4] but clearly seen in the γ channel.[6] $J^\pi=4^+$ assignment is eliminated and 2^+ is preferable in the channel. The 2^+ resonance of the doublet may be the same one in the γ channel. Later we will discuss this resonance. In the α spectrum[11] a strong peak at $E_x(^{24}Mg)\approx 22.0$ MeV corresponds to this doublet.

8.88 and 9.08 MeV. $|P_6(\cos\theta)|^2$ reproduces these angular distributions very well. Their J^π values are both 6^+. These resonances have been observed in the α channel,[4] and our J^π assignments are consistent with those of the α channel. The latter is also reported in the ^{8}Be channel by James *et al.*[10]

9.34, 9.56, and 9.70 MeV. The angular distributions are also well fitted by $|P_6(\cos\theta)|^2$. Their J^π values are all 6^+. These three resonances are not clearly seen in the α exit channel[2,4] nor reported by James *et al.*[10] However, we can find two peaks in the α spectrum[11] at corresponding energies ($E_x=23.2$ and 23.5 MeV). The latter two resonances are unresolved in the spectrum.

9.99 MeV. The angular distribution is not well fitted by $|P_6(\cos\theta)|^2$. The dotted line in Fig. 3(s) is obtained by the parameter set of formula (3), ($L1=6$, $L2=4$, $A=0.3$, $\phi=30°$). This shows that $L=6$ wave is dominant in the resonance. This is also reported by James *et al.*[10] In the α exit channel this has not been observed,[2,4] but in the α spectrum[11] a rather strong peak can be found at $E_x(^{24}Mg)=23.8$ MeV.

10.29 and 10.43 MeV. These two angular distributions resemble one another and are not well reproduced by $|P_8(\cos\theta)|^2$. The fits by formula (3) are unsuccessful. James *et al.*[10] reported that the resonances at 10.30 and 10.45 MeV had $J^\pi=8^+$ and 6^+, respectively, but they determined these values only by the data at four backward angles. We feel that the most plausible J^π assignments for the two resonances are both 8^+. They have not been identified in the α exit channel.[2,4] In the α spectrum[11] they seem to correspond to a peak at $E_x(^{24}Mg)=24.2$ MeV.

10.68 and 10.98 MeV. $|P_8(\cos\theta)|^2$ reproduces the angular distributions very well. The resonance have $J^\pi=8^+$. They are observed in the α and ^{8}Be channels. Our J^π assignments agree with these results. The two resonances also correspond to the two peaks at $E_x(^{24}Mg)=24.7$ and 24.9 MeV in the α spectrum.[11]

In Fig. 4, our results are summarized and compared with those of Refs. 2, 4, 6, and 11.

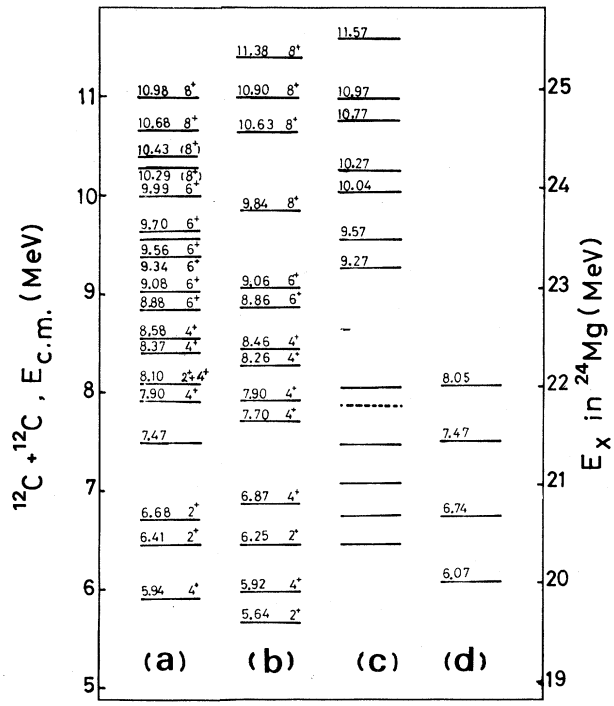

FIG. 4. Summary of our results and those of Refs. 2, 4, 6, and 11. (a) Present work. (b) The α exit channel (Refs. 2 and 4). (c) The reaction $^{12}C(^{16}O,\alpha)^{24}Mg$ (Ref. 11). (d) The γ channel (Ref. 6).

C. Angle integrated cross section

Angle integrated cross section on the resonances are calculated under the assumption that the angular distributions are fully reproduced by formula (1). The values are given in Table I. It is worth comparing them to those of the α channel. Voit *et al.*[4] have reported integrated cross sections in $^{12}C(^{12}C,\alpha)^{20}Ne$ summed up for the 10 or 11 transitions to ^{20}Ne. Integrated cross sections of the resonances in the α channel are estimated to be about 50 ~ 100 mb. Considering the difference of the penetrability between the α and ^{8}Be channels, integrated cross sections of both exit channels indicated that the reduced widths of the ^{16}O-^{8}Be channel are as large as those of the α channel.

IV. DISCUSSION

A glance at Fig. 4 shows that the resonances with the same J^π values are clustered in the ^{16}O-^{8}Be and α channel. They seem to form gross structures with a unique L value. The same picture, as Fletcher *et al.*[21] have found at higher energy region, also exists here. Cormier *et al.*[22] have reported that these gross structures continue to a much higher energy region and likely form a band structure. Recently, the picture has been applied partially to the $^{12}C+^{16}O$ system.[23,24] It is worth comparing the structures between the ^{16}O-^{8}Be and α channels. Their energies with the same L values agree well between these. This fact may show that their L values are determined in the entrance channel, because the grazing angular momenta between the two exit channels are different and the difference is expected to be reflected in the structures, if they are selected in the exit channel. This may suggest that intermediate resonances are led by shape resonances in the entrance channel.

Next we can find an interesting relation between the γ, α, and ^{16}O-^{8}Be channels; namely the resonances appearing in our data seem to correlate complementarily with the other two channels. For instance, the resonances at 5.94, 6.41, and 7.90 MeV are seen in the α channel, but not in the γ one. In opposition, the ones at 6.68, 7.47, and 8.10 MeV appear in the γ channel, but not in the α one. This suggests that the resonances in the ^{16}O-^{8}Be channel can be observed in the γ channel only when the decay to the α channel is suppressed. This makes us believe that resonant states do not always decay equally to all possible exit channels. This is a proper example the criterion (ii) is too severe.

This relation gives us some information about structures of these resonances. In the α channel, energies at 6.68, 7.47, and 8.10 MeV correspond to those of strong minima in the summed excitation functions in Ref. 4. This correspondence forms a striking contrast to those of the other resonances. For example, the resonances at 9.34 and 9.56 MeV seen in the ^{16}O-^{8}Be channel have not been identified in the α channel in Ref. 4, nevertheless they correspond to small but clear peaks in those excitation functions. Thus the resonances at 6.68, 7.47, and 8.10 (2^+) MeV may have characteristic nature. Tohsaki-Suzuki[18] has studied the role of 0_1^+ (7.66 MeV) of ^{12}C nucleus in the molecular resonances of the $^{12}C+^{12}C$ system by microscopic calculation and has shown that the 0_1^+ state possibly plays an important role in the resonances; namely the $^{12}C_{g.s.}+^{12}C_{g.s.}$ configuration has a good overlap with the $^{12}C_{g.s.}+^{12}C^*$ (0_1^+) one at the contact distance, and the latter also overlaps well with the $^{16}O+^{8}Be$ configuration and poorly with the α+Ne one. The above three resonances can be considered to be the resonance with this structure.

The other interesting result is the good correspondence between the resonances in our data and the levels in the α spectrum of the reaction $^{12}C(^{16}O,\alpha)^{24}Mg^*$,[11] which has been already referred. Lazzarini *et al.* have also mentioned the fact that the levels in the α spectrum correspond to the resonances in the α and ^{8}Be channels at a higher energy region in their paper.[11] We cannot say strictly at this stage whether the correspondences have a physical origin or not, because even J^π values of the levels in the α spectrum are unknown. But the good agreements in energy strongly suggest that the resonances in our data are true states of ^{24}Mg.

V. SUMMARY

Several resonances have been identified in the $^{12}C+^{12}C$ system through the reaction $^{12}C(^{12}C,^{16}O_{g.s.})^{8}Be_{g.s.}$ and J^π values have been assigned to them as follows: 5.94 MeV (4^+), 6.41 MeV (2^+), 6.68 MeV (2^+), 7.90 MeV (4^+), 8.10 MeV (2^++4^+), 8.37 MeV (4^+), 8.58 MeV (4^+), 8.88 MeV (6^+), 9.08 MeV (6^+), 9.34 MeV (6^+), 9.56 MeV (6^+), 9.70 MeV (6^+), 9.99 MeV (6^+), 10.29 MeV (8^+), 10.43 MeV (8^+), 10.68 MeV (8^+), and 10.98 MeV (8^+). An interesting relation has been found among the γ, α, and ^{16}O-^{8}Be channel. Good correspondences in energy have been seen between the resonances in the ^{16}O-^{8}Be channel and the γ channel, and between the former and the levels in the α spectrum in the reaction $^{12}C(^{16}O,\alpha)^{24}Mg^*$ in Ref. 11. They strongly suggest that the resonances in the ^{16}O-^{8}Be channel are true states of ^{24}Mg.

ACKNOWLEDGMENTS

The authors wish to acknowledge many stimulating discussions with Professor Y. Abe and useful comments with Prof. H. Horiuchi. We are also indebted to Professor S. Kobayashi for his encouragement and to the staffs in our laboratory for their discussions.

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