Resonances in $^{12}C(^{12}C,\alpha)^{20}Ne$†

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Excitation functions for $^{12}C(^{12}C,\alpha)^{20}Ne$ show a number of strongly correlated resonances in the c.m. bombarding-energy range 17–20 MeV, all with widths of ~300–400 keV.

[NUCLEAR REACTIONS $^{12}C(^{12}C,\alpha)$, $E=34-51$ MeV, measured $\sigma(E)$, $\theta=5°$ (lab). Five correlated resonances in energy range 34–40 MeV.]

In a detailed study of the mechanism[1] of the $^{12}C(^{12}C,\alpha)^{20}Ne$ reaction for center-of-mass (c.m.) bombarding energies of 17–25.5 MeV, comparison with Hauser-Feshbach calculations indicated the presence of a strong direct mechanism for certain states. A significant compound-nucleus component was also present. Cross correlations, calculated for the entire energy range, were largely statistical. However, in the energy range 17–20 MeV there appeared several isolated, strongly correlated resonances, each more pronounced than that observed recently[2] in $^{12}C(^{12}C,p)^{23}Na$. We report on them here.

Excitation functions for the $^{12}C(^{12}C,\alpha)^{20}Ne$ reaction leading to final states below 17 MeV in excitation were measured at a laboratory angle of 5° in energy steps of 62.5 keV (c.m.) from a c.m. bombarding energy of 17 to 25 MeV. In the bombarding-energy range 17–20 MeV (c.m.) a number of large peaks in the cross section were observed. Some of these peaks are present in a number of different $\alpha+^{20}Ne$ channels, prompting us to believe that they correspond to actual states in ^{24}Mg which are being formed as $^{12}C+^{12}C$ resonances. On-resonance-to-off-resonance ratios are as large as 120 to 1. Similar effects have been observed recently in $^{16}O(^{12}C,\alpha)$ (Ref. 3), $^{12}C(^{13}C,\alpha)$ (Ref. 4), $^{12}C(^{12}C,p)$ (Ref. 2), and $^{10}B(^{14}N,\alpha)$ (Ref. 5) but nothing so striking as here. Strong resonancelike structure has just recently[6–8] been observed in $^{12}C(^{12}C,{}^{8}Be)$. Each of the present resonances occurs in more open channels and has larger on-resonance enhancements in the cross section than that observed recently[2] in $^{12}C(^{12}C,p)^{23}Na$.

Some of the 5° (lab) excitation functions are dis-

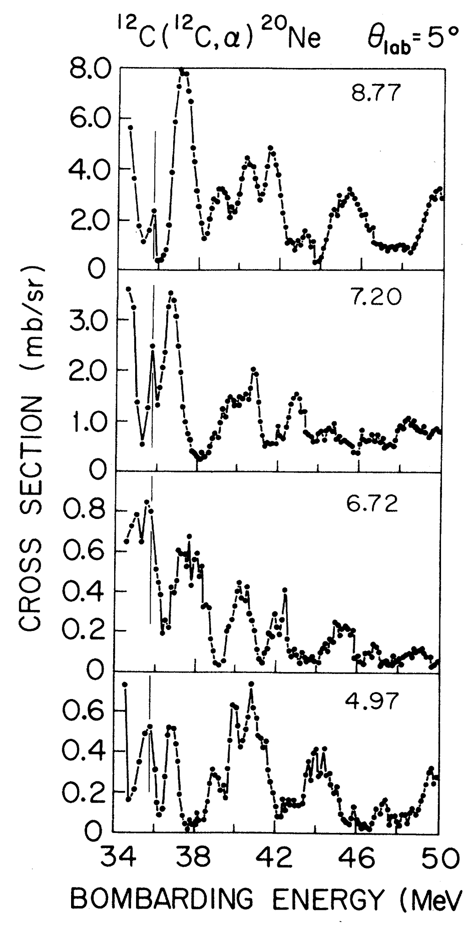

FIG. 1. Excitation functions for the reaction $^{12}C(^{12}C,\alpha)^{20}Ne$ exhibiting the resonance at 17.9 MeV c.m.

played in Figs. 1–5. Prominent correlated resonances occur at c.m. bombarding energies of 17.9, 18.4, 18.6, 19.0, and 19.4 MeV. The cross-section peak at 17.9 MeV (Fig. 1) is definitely present for four final states—4.97, 6.72, 7.20, and 8.77 MeV and perhaps present for two others—4.25 and 9.04 MeV. It is the least pronounced of the resonances reported here.

Perhaps the most prominent resonance is at 18.4 MeV. It occurs (Fig. 2) with striking clarity for seven final states: ground state (g.s.), 4.97, 7.01, 7.20, 7.83, 9.04, and 15.20 MeV, and is probably present for a number of other states, viz., 8.45, 11.95, 12.40, 13.07, and 14.34 MeV. In the latter set, the structure is more complicated due to the presence of other nearby peaks in the cross section. The position of the resonance in the former set of yield curves agrees to within $\frac{1}{2}$ step size (30 keV c.m.) for all seven states. A statistical

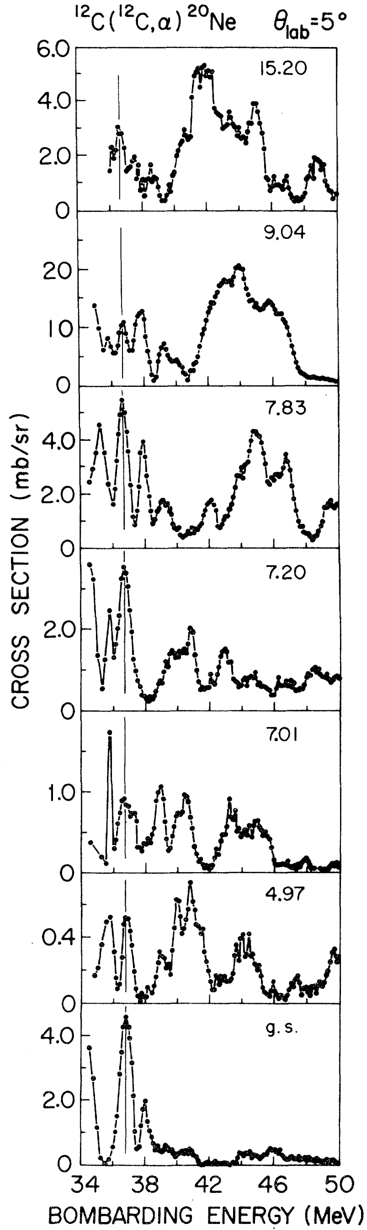

FIG. 2. Excitation functions for the reaction $^{12}C(^{12}C,\alpha)^{20}Ne$ leading to those final states that show the 18.4-MeV resonance.

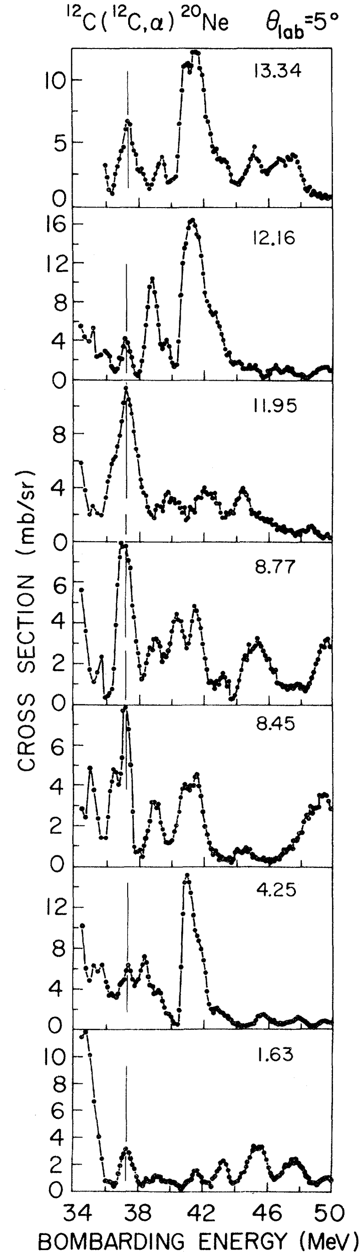

FIG. 3. Same as Fig. 1 and 2 but for the 18.6-MeV resonance.

analysis indicates that the probability that this effect is a manifestation of fluctuations is less than 10^{-8}.

The resonance at 18.6 MeV (Fig. 3) is also present for seven final states, *all of which are different from those showing the 18.4-MeV resonance.* Those exhibiting the 18.6-MeV resonance are states at 1.63, 4.25, 8.45, 8.77, 11.95, 12.16, and 13.34 MeV. Four of these states are in the g.s. band. There is a hint of an enhancement at this bombarding energy for four other final states—5.62, 6.72, 7.01, and 7.42 MeV.

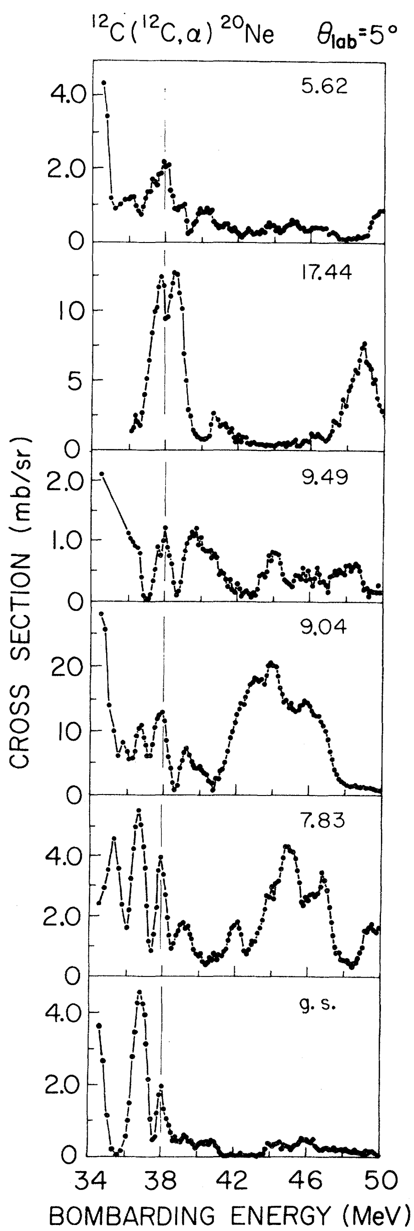

FIG. 4. Same as previous figures but for the 19.0-MeV resonance.

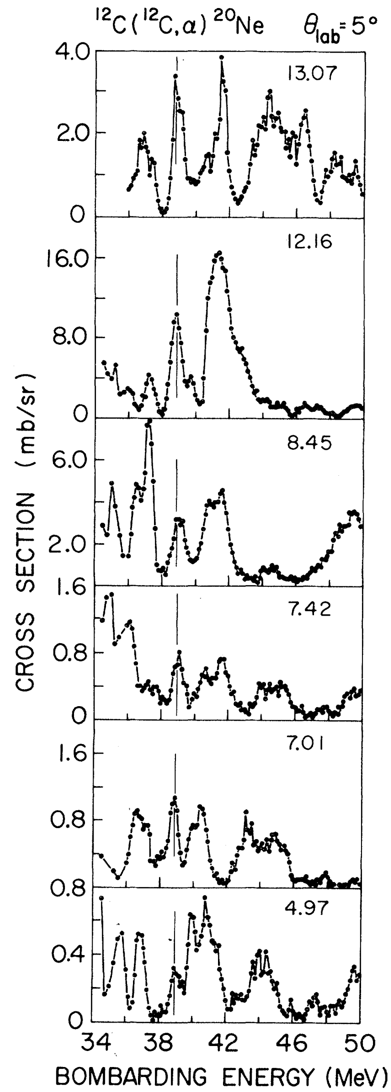

FIG. 5. Same as previous figures, but for the 19.4-MeV resonance.

The 19.0-MeV resonance (Fig. 4) is present very clearly for four states—at 0.0, 7.83, 9.04, and 9.49 MeV, and not so clearly for two others, at 17.44 and 5.62 MeV. The first three of these states

TABLE I. Energies and widths of resonances in $^{12}C(^{12}C,\alpha)^{20}Ne$.

E_{res}(lab) (MeV)	E_{res}(c.m.) (MeV)	$E_x(^{24}Mg)$ (MeV)	Γ(c.m.) (keV)
35.88	17.9	31.8	340 ± 60
36.80	18.4	32.3	400 ± 30
37.25	18.6	32.5	375 ± 100
38.00	19.0	32.9	310 ± 60
38.88	19.4	33.3	320 ± 30

TABLE II. α decays of resonances in $^{12}C + ^{12}C$.

$E_x(^{20}Ne)$ (MeV)	J^π	K^π	E_{res}(c.m.) (MeV) 17.9	18.4	18.6	19.0	19.4
0.0	0^+	0_g^+	No	Yes	No	Yes	No
1.63	2^+	0_g^+	No	No	Yes	No	No
4.25	4^+	0_g^+	Maybe	No	Yes	No	No
4.97	2^-	2^-	Yes	Yes	No	No	Yes
5.62	3^-	2^-	No	No	Maybe	Maybe	Maybe
5.78	1^-	0^-	No	No	No	Maybe	Maybe
6.72	0^+	0_1^+	Yes	No	Maybe	Maybe	No
7.00	4^-	2^-	No	Yes	Maybe	Maybe	Yes
7.17	3^-	0^-	Yes	Yes	No	No	No
7.20	0^+	0_2^+	Yes	Yes	No	No	No
7.42	2^+	0_1^+	No	No	Maybe	No	Yes
7.83	2^+	0_2^+	No	Yes	No	Yes	No
8.45	5^-	2^-	No	Maybe	Yes	No	Yes
8.78	6^+	0_g^+	Yes	No	Yes	No	No
9.04	4^+	0_2^+	Maybe	Yes	No	Yes	No
9.49	2^+	···	No	No	No	Yes	No
9.99	4^+	0_1^+	No	No	No	No	Maybe
11.95	8^+	0_g^+	No	Maybe	Yes	No	No
12.16	6^+	0_2^+	No	No	Yes	No	Yes
"12.40"	6^+	0_1^+	No	Maybe	No	No	Maybe
13.07	(4^+)	···	No	Maybe	No	No	Yes
13.34	7^-	2^-	No	No	Yes	Maybe	No
13.95	···	···	No	No	No	No	Maybe
14.34	(6^+)	···	No	Maybe	No	No	No
15.20	···	···	No	Yes	No	No	Maybe

also exhibit the 18.4-MeV resonance, and none possess any of the other resonances.

Finally, a resonance at 19.4 MeV (Fig. 5) occurs clearly for six final states—those at 4.97, 7.01, 7.42, 8.45, 12.16, and 13.07 MeV, and perhaps for a few others at 5.62, 5.78, 9.99, 12.40, 13.95, and 15.20 MeV.

The energies and widths of these five resonances are summarized in Table I. A number of additional large peaks are present in the cross section at higher bombarding energies, but none with such clear correlations among various channels. Perhaps the most notable of these is near 21 MeV c.m. A large bump is present there for at least 10 states, but the peaks are not at the same energy for the various channels. If this is a resonance phenomenon, then overlapping resonances must be present.

It may be that some indications of the microscopic structure of these lower five resonances are to be found in their decay channels, which are summarized in Table II. For example, only two of the resonances (at 18.4 and 19.0 MeV) decay to the g.s. These two and no others also decay to the 7.83- and 9.04-MeV states, the 2^+ and 4^+ members of a core-excited band.

The 2^+ and 4^+ members of the g.s. band, at 1.63 and 4.25 MeV, exhibit only the 18.6-MeV resonance. It is perhaps noteworthy that the 6^+ and 8^+ members of the g.s. band also show this resonance. In fact, except for the 12.16-MeV state, all the states that show this resonance are either in the g.s. band or in the 2^- band.

Three members of the 8p-4h band and two members of the 2^- band exhibit the 18.4-MeV resonance, in addition to the g.s.

None of these resonances occur at the energy 19.3 MeV of the $^{12}C(^{12}C,p)^{23}Na$ resonance of von Bibber *et al.*[1] In fact, most of the $\alpha + ^{20}Ne$ excitation functions exhibit[9] a correlated minimum at that energy.

The fact that several of the resonances show up for 0^+ final states makes it possible to determine their spins. Angular distributions measured on resonance should be dominated by $P_J^{\,2}(\cos\theta)$, where J is the spin of the resonance. Such a study is made easier by the fact that selection rules in the present reaction limit J to even values and parity to positive. This investigation is underway. Reactions in the same bombarding-energy range and preliminary angular-distribution measurements[10,11] indicate that they all have high spin, $J = 8$, 10, or 12. A number of resonancelike structures observed[6–8] in $^{12}C(^{12}C,{}^8Be)^{16}O$ (g.s.) also exhibit angular distributions that are dominated by large L values, 8, 10, or 12. However, it is not possible to make a one-to-one identification of the resonances observed in $^{12}C(^{12}C, \alpha)$ with the structures observed in $^{12}C(^{12}C, {}^{8}Be)^{16}O$ (g.s.).

In fact, a recent report casts doubt on the interpretation of one of these "bumps" as a true resonance. At a c.m. energy of 18.5 MeV, the $^{12}C(^{12}C, \alpha)^{20}Ne$ (g.s.) angular distribution was dominated[7] at forward angles by $L = 10$, whereas that for $^{12}C(^{12}C, {}^{8}Be)^{16}O$ (g.s.) was characterized more by $L = 12$. Clearly, much more work is needed before the nature of these phenomena can be well understood.

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