Resonances in the $^{12}\text{C}(^{12}\text{C,}^{8}\text{Be}_{g.s.})^{16}\text{O}$ reaction and rotational states in $^{24}\text{Mg}$

M. Lattuada$^{(1)}$, E. Costanzo$^{(1)}$, A. Cunsolo$^{(1)}$, A. Foti$^{(1)}$
S. Romano$^{(1)}$, C. Spitaleri$^{(1)}$, A. Tumino$^{(1)}$
D. Vinciguerra$^{(3)}$ and M. Zadro$^{(3)}$

$^{(1)}$ Istituto Nazionale di Fisica Nucleare, L.N.S. and Sezione di Catania - Catania, Italy
$^{(2)}$ Università di Catania - Catania, Italy
$^{(3)}$ Rudjer Bošković Institute - Zagreb, Croatia

Summary. — The results of a set of experiments on the $^{12}\text{C} + ^{12}\text{C} \to ^{8}\text{Be}_{g.s.} + ^{16}\text{O}$ excitation function between 20 and 36 MeV c.m. beam energy are summarized and discussed. A set of 1 MeV wide resonances shows up in the energy range investigated, all of them following the rotational rule with a coefficient of inertia consistent with a $^8\text{Be} - ^{16}\text{O}$ configuration.

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1. – Introduction

When speaking of $^{12}\text{C} + ^{12}\text{C}$ resonances, the starting point is often the historical data by Almqvist et al. [1], first evidence for intermediate width resonances in heavy-ion collisions, interpreted as due to the formation of a dinuclear system in rotational states. Since then a lot of experimental and theoretical work has been done on quasi-molecular resonances in light-medium ion collisions (see, for example, ref. [2, 3]). Special attention has been devoted to the $^{12}\text{C} + ^{12}\text{C}$ system, which is still able to show unexpected features. The data showed here are connected with recent experimental evidences on the excitation function of the $^{12}\text{C} + ^{12}\text{C} \to ^{12}\text{C}(^6\text{He}^+) + ^{12}\text{C}(^6\text{He}^+) \to 6\alpha$ reaction around 32.5 MeV c.m. energy, which in a first interpretation were considered as an indication of the formation of a linear $\alpha$-chain state in $^{24}\text{Mg}$ at 46.4 MeV [4].

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Even if now, after a few years, different interpretations have been proposed, at that
time the nice 5 MeV wide peak found at $E_{cm.} = 32.5$ MeV and the associated angular distrib-
utions suggested an interpretation in terms of excitation of degenerated states of $^{24}$Mg
around 46.4 MeV, belonging to a rotational band with a very large moment of inertia as
the one expected for a shape of six $\alpha$'s on a line. A number of reasons led to this inter-
pretation: i) existent predictions of such state for example, due to the Cranked Cluster
Model [5] and associated to a minimum of the Nilsson-Strutinsky energy surface; ii) need
of several partial waves to reproduce the behavior of the angular distribution, in partic-
ular around 90$^\circ$; iii) attribution of a very deformed shape to $^{12}$C($0^{+}_2$) with a linear chain
component by the Bloch-Brink model [6]. Deeper studies of different final states were
performed after this finding and several inelastic and transfer channels were found to
resonate at or close to that energy (see for example refs. [7-10]), stimulating search for
alternative interpretations which are still matter of a wide debate.

The Cranked Cluster Model [5] predicts a crossing of the linear chain band with the
one associated with the less deformed configuration described as a spherical $^{16}$O core plus
two $\alpha$'s, the so-called $D_1$ configuration, at an energy close to the energy of the Wuosmaa
resonance, thus suggesting the possible competition of $^{24}$Mg decay into many channels
with different degrees of deformation.

From these indications it seemed to us interesting to study the excitation function of
another exit channel of the $^{12}$C + $^{12}$C interaction, which could be related to the $D_1$ con-
figuration, namely the $^{8}$Be$_{g.s.} + ^{16}$O$_{g.s.}$ one.

2. – Experiments and data analysis

Several experiments were performed in different times and with different detection
setups, using $^{12}$C beams accelerated by the SMP Tandem Van de Graaff of Laboratorio
Nazionale del Sud, Catania, and natural C targets of thickness ranging from 100 to 300
$\mu$g/cm$^2$.

All the experiments were performed by using silicon Position Sensitive Detectors (PSD) arranged in different ways. Some of the data showed here were collected by iden-
tifying $^{16}$O by means of ionization chambers placed in front of PSDs. In this case the wide
$^{8}$Be first excited state gives some background under the ground state peak and the exci-
tation energy spectrum is complicated by the presence of peaks due to the excitation of both $^{8}$Be and $^{16}$O (the last one under the threshold for $\alpha$-decay). Other data were taken
by identifying $^{8}$Be$_{g.s.}$ ions by means of the same telescopes. In this case it was the locus
in the $E$-$\Delta E$ plane corresponding to the 2 $\alpha$-particle detection of a $^{8}$Be$_{g.s.}$ ion near the
$Z = 3$ locus. Lithium ions produced in the $^{12}$C + $^{12}$C interaction have low energy and do
not overlap the events due to the simultaneous detection of the $\alpha$-particles produced by
the decay of $^{8}$Be$_{g.s.}$, at least when the recoil $^{16}$O ion is left at the lower excited states. Then
the $^{8}$Be spectrum is cleaner, but there is again a limitation in the $^{16}$O excitation energy.

A third way of measuring the final state under consideration consisted in the coincident
detection of each of the two $\alpha$-particles emitted by $^{8}$Be by each of the two halves of a Dual
PSD (DPSD). The $^{8}$Be is clearly identified from the relative energy spectrum of the two $\alpha$-
particles, as it is shown in fig. 1. In this case the whole accessible $^{16}$O excitation spectrum
is unambiguously measured (fig. 2). In the last two cases detection efficiency has been
calculated and data have been corrected accordingly. Of course, in both cases, efficiency
for detection of higher excited states of $^{8}$Be is very poor, because of the much larger $\alpha$
emission cone with respect to the ground-state one.