Communications

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$^{12}C(^{12}C,t)^{21}Na$ reaction between 37 and 50 MeV

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The $^{12}C(^{12}C,t)^{21}Na$ reaction has been studied at $\theta = 0°$ over an energy range from 37 to 50 MeV. Rapid fluctuations in the cross sections to individual final states were observed, but no conclusive evidence for pronounced resonant structure was observed, either at the 19.3 MeV (c.m.) anomaly or elsewhere.

[NUCLEAR REACTIONS $^{12}C(^{12}C,t)$; $E=37-50$ MeV, measured $\sigma(E,E_t,\ \theta=0°)$. ^{21}Na deduced levels.]

A great deal of attention has been devoted in the last few years to the $^{12}C+^{12}C$ system. The interest centers around the quasimolecular resonance phenomenon[1] and many anomalies[2] have been discovered in the p, n, d, α, and ^8Be exit channels, as well as in the elastic and inelastic scattering. A recent review of this research is given in Ref. 1. Elucidation of the nature of these anomalies requires the study of as many exit channels as possible.

In this communication we report a study of the $^{12}C(^{12}C,t)\,^{21}Na$ reaction in a region of bombarding energy where a number of anomalies have been reported,[2] viz., between 37 and 50 MeV (lab). The present experiment represents the first observation of a three-nucleon exit channel in the $^{12}C+^{12}C$ reaction. The Q value of this reaction is very negative: $Q=-12.765$ MeV and hence only the low-lying states of ^{21}Na are above threshold at the lower range of bombarding energies.

Beams of ^{12}C ions were obtained from a sputter source and accelerated by the McMaster University FN tandem accelerator. Thin targets (~20 $\mu g/cm^2$) of natural carbon were evaporated onto 0.025 cm Al foils which served to stop the beam and allow the current to be measured. The outgoing particles were detected at 0° in a three component counter telescope consisting of 100μ and 200μ ΔE and 3 mm E surface barrier detectors. Particle identification was carried out with an on-line com-

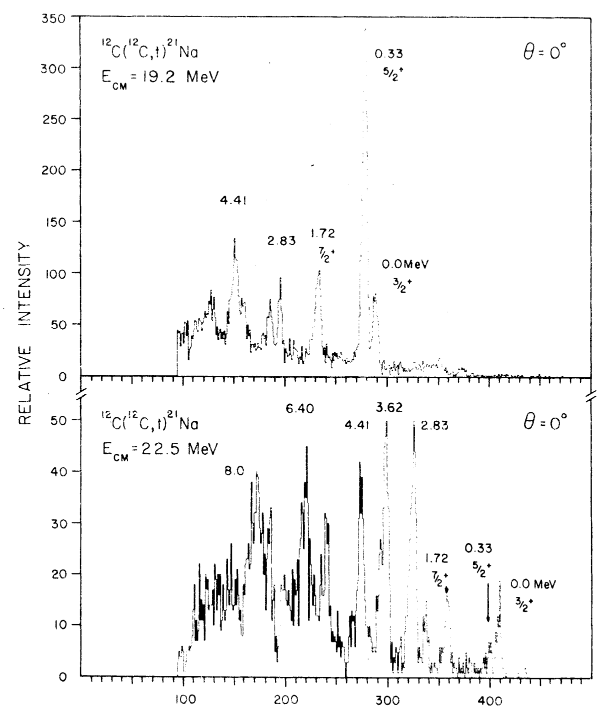

FIG. 1. Spectra of the $^{12}C(^{12}C,t)^{21}Na$ reaction taken at an angle of 0° and incident bombarding energies of (a) 38.4 MeV and (b) 45 MeV.

puter using empirical energy-loss tables for tritons. Protons, deuterons, and tritons were well resolved in the particle identification spectrum, but the very weak ^3He group was masked by the extremely intense yield of α particles. Hence clean ^3He spectra could not be obtained. Typical spectra of tritons, taken at bombarding energies of 19.2 and 22.5 MeV (c.m.), are presented in Figs. 1(a) and 1(b).

A well-established resonance-type anomaly exists in the p, n, d, and α-particle exit channels at 19.3 MeV, and has been extensively studied.[2] The nucleon decay proceeds to $15/2^+$ and $17/2^+$ states in the mass-23 nuclei, while deuteron emission proceeds predominantly to a 7^+ state in ^{22}Na.

The yield of tritons as a function of bombarding energy to individual excited states of ^{21}Na is shown in Fig. 2. Rapid and large fluctuations in these yields are observed between 18.5 and 20.0 MeV (c.m.), but there is no evidence of an anomaly near the 19.3 MeV "resonance", except for a deep minimum in the yield to the 1.72 MeV $7/2^+$ state.[3] Since the "anomaly" only occurs in one final state, it is most likely an Ericson fluctuation and not evidence of a true resonance. We conclude that there is no unambiguously observable resonance in the yield of tritons to low-lying states in ^{21}Na near 19.3 MeV bombarding energy.

States in ^{21}Na above 7.23 MeV are below the reaction threshold at $E_{c.m.} = 20$ MeV, but should be populated at higher bombarding energies. In Fig. 1(b) we present a spectrum of tritons at $E_{c.m.} = 22.5$ MeV. The low-lying states ($E_x < 4$ MeV) are very weakly populated at high bombarding energies, but a number of states above 4 MeV excitation are seen to be strongly excited.[4] Yield curves for the high-lying levels are presented in Fig. 2 at 0.5 MeV (c.m.) intervals between 21 and 25 MeV. As at lower energies, there are large fluctuations in the cross sections but few systematic anomalies can be deduced from the data. The largest such

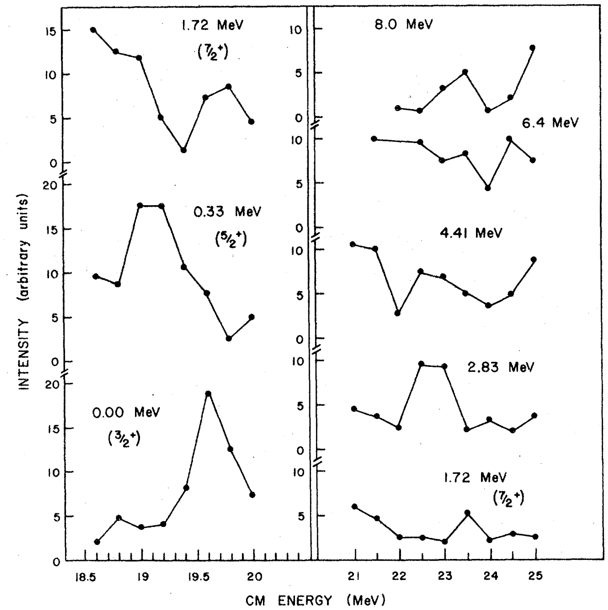

FIG. 2. Excitation functions for a number of excited states of ^{21}Na observed in the $^{12}C(^{12}C,t)$ reaction.

"bump," at ~45 MeV in the yield to the 2.83 MeV state, does seem to be present in some other exit channels. Cosman *et al.*[2] show that a number of excited states in ^{23}Na and the 7^+ level in ^{22}Na "resonate" around 22–23 MeV (c.m.) in the proton and deuteron channels, respectively. But this structure is not nearly so pronounced nor so well correlated as the 19.3 MeV anomaly, and therefore might only be a fluctuation.

In summary, no conclusive evidence for resonance-style anomalies persisting in several exit channels has been found in the $^{12}C(^{12}C,t)$ reaction in an energy range where such enhancements in yield have been observed for outgoing protons, deuterons, and α particles. The nature of these anomalies is still unclear and much further work is required if their structure is to be understood.

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[1] D. A. Bromley, in *Proceedings of the International Conferences on Resonances in Heavy Ion Reactions, Hvar, Yugoslavia*, edited by N. Cindro (North-Holland, Amsterdam, 1978).

[2] K. van Bibber *et al.*, Phys. Rev. Lett. 32, 687 (1974); E. R. Cosman *et al.*, *ibid.* 35, 265 (1975); G. KeKelis and J. D. Fox, Phys. Rev. C 10, 2613 (1974); T. M. Cormier *et al.*, Nucl. Phys. A247, 377 (1975).

[3] P. M. Endt and C. van der Leun, Nucl. Phys. A310, 1 (1978).

[4] The prominent structures at 4.41 and 6.40 MeV may correspond to the $J^\pi = \frac{11}{2}^+$ and $\frac{13}{2}^+$ members of the ground-state band in ^{21}Na. Their ^{21}Ne analogs are known (Ref. 3) to lie at 4.43 and 6.45 MeV, respectively.