PHYSICAL REVIEW C VOLUME 52, NUMBER 2 AUGUST 1995

COMMENTS

Comments are short papers which criticize or correct papers of other authors previously published in the **Physical Review**. *Each Comment should state clearly to which paper it refers and must be accompanied by a brief abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

^{4}H clustering in lithium nuclei

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(Received 26 July 1994)

In response to a recent paper by Becchetti *et al.* it is shown that there are several experimental and theoretical evidences about the ^{4}H clustering in lithium nuclei.

PACS number(s): 27.20.+n, 21.60.Gx, 25.55.Hp, 25.70.Hi

The aim of this Comment is to point out several pieces of evidence and indications about the ^{4}H clustering in lithium nuclei, which have very often been overlooked or ignored. It is motivated by a recent paper by Becchetti *et al.* [1]. They have reported an experimental study of the (^{8}Li,α) reactions on ^{12}C and ^{9}Be at 14 MeV. In the case of the ^{12}C(^{8}Li,α)^{16}N reaction Becchetti *et al.* observe a strong emission of α particles to a group of levels near the ground state of ^{16}N. They state '...we cannot attribute (^{8}Li,α) cross sections to contributions from a direct cluster-transfer mechanism as this would require transfer of a ^{4}H "cluster." This seems unlikely since, as noted, ^{8}Li has the dominant spectroscopic structure $^7\mathrm{Li}+n = (\alpha + t) + n$, where the triton and neutron are not particularly spatially correlated.' One should disagree with these statements and repeat arguments about clustering in ^{8}Li similar to those by Amado and Noble [2], who pointed out the equivalence rather than the mutual exclusion of the ^{3}He-t and d-α descriptions of ^{6}Li. A large spectroscopic factor for n-^{7}Li does not imply a small ^{4}H-α overlap with ^{8}Li. As was shown [3] in the $(1s)^4(1p)^4$ oscillator shell model the spectroscopic factors for the $L^\pi = 1^+$ state (the ^{8}Li 2^+ ground state is an $L = 1^+$ state with $S = 1$) with respect to n-^{7}Li and α-^{4}H cluster configurations are 1.52 and 1, respectively. [In the model the states with $L^\pi = 1^+, 2^+, 3^+$ can be constructed having either $S = 0$ or $S = 1$ for spatial symmetry $[f] = [431]$ and SU$_3$ symmetry $(\lambda\mu) = (21)$.] In the same paper in a multiconfiguration resonating group theory of ^{8}Li the ^{4}H-α configuration (together with n-^{7}Li, t-^{5}He, and n-^{7}Li*) had to be taken into account in order to improve the agreement with experimental data. It should be added that, according to these calculations, the ^{7}Li(n,^{4}H)^{4}He reaction cross section is about 25% of the total $n+^7$Li reaction cross section at neutron energies around 20 MeV.

Becchetti *et al.* add that, although forward-peaked angular distributions in the (^{6}Li,α) and (^{7}Li,α) reactions are attributed to direct transfer of a deuteron and triton, in the (^{8}Li,α) reaction "direct ^{4}H transfer does not seem plausible" and they compare the data with a $1/\sin(\Theta_{\mathrm{c.m.}})$ distribution expected for a compound nucleus (CN) reaction. Without doing elaborate distorted-wave Born approximation (DWBA) calculations, one can also compare the results with the $j_l^2(\mathbf{q}\cdot\mathbf{R})$ behavior of a direct reaction (DR) (see, e.g., [4]). For the calculation an $l = 1$ ^{4}H transfer and $R = 4$ fm are assumed. Both $1/\sin(\Theta_{\mathrm{c.m.}})$ and $j_1^2(\mathbf{q}\cdot\mathbf{R})$ are shown on Fig. 1 together with the experimental data. The curves are normalized to the data in the following way: CN, in the same way as in [1] (to 1 at 90°); DR, to the first maximum (which was the standard practice for the plane-wave Born approximation (PWBA)

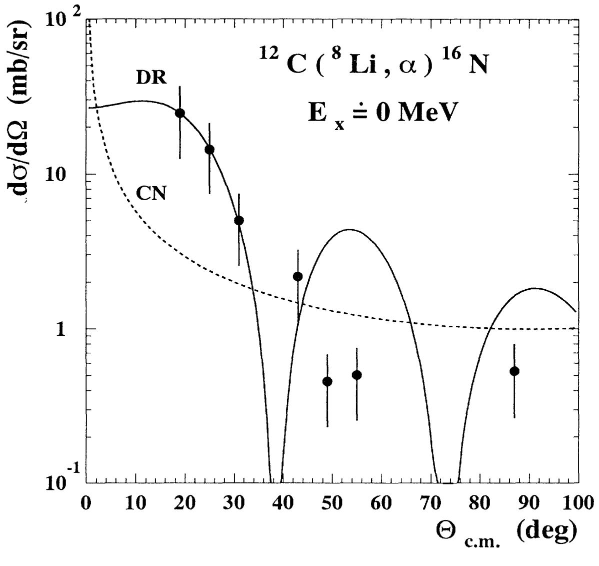

FIG. 1. Experimental angular distribution for the reaction ^{12}C(^{8}Li,α)^{16}N($E_x \doteq 0$) at $E(^8\mathrm{Li}) \doteq 14$ MeV compared with the $1/\sin(\Theta_{\mathrm{c.m.}})$ distribution expected for a compound nucleus reaction (CN) and the $j_1^2(\mathbf{q}\cdot\mathbf{R})$ distribution expected for a direct reaction (DR).

0556-2813/95/52(2)/1140(2)/$06.00

calculations). One can see which of the crude theories better describes the behavior of the experimental results and why the ^{4}H clustering in ^{8}Li should not be ignored.

Besides ^{8}Li there are even more indications that ^{4}H clustering is also important for the ^{7}Li nucleus. In this case, ^{4}H-^{3}He relative motion can be in either the $2S$ or $1D$ state. The most important evidence (although not explicitly stated) came from a study of the ^{7}Li breakup by ^{3}He at 120 MeV [5]. The experimental setup in the measurements emphasized ^{3}He-^{3}He quasifree scattering kinematic conditions, i.e., in a large part of the available phase space the third "particle" (^{4}H) momentum had very small values. This fact coupled with a relatively high bombarding energy is responsible for revealing this strongly bound ($E_B \approx 26$ MeV) ^{3}He-^{4}H clustering mode.

In the (^{3}He,$t\,^3$He) reaction, besides the ^{4}He ground state peak, another prominent peak was observed at excitations around 22 MeV. It should be at least in a part attributed to the other member of the same $(A=4)_{T=1}$-$(A=3)_{T=1/2}$ clustering mode in ^{7}Li, i.e., $^4\mathrm{He}_{T=1}$-t. Also, all this explains in a natural way why in these kinematical conditions the cross sections for the ^{7}Li(^{3}He,^{3}He$\,^3$He)^{4}H$_{\mathrm{g.s.}}$ and ^{7}Li(^{3}He,$t\,^3$He)^{4}He* ($E_x \approx$ 22 MeV), are of the same order of magnitude as well as why the (^{3}He,^{3}He$\,^3$He) is more than an order of magnitude stronger than its symmetric ^{7}Li(^{3}He,tt)^{4}Li$_{\mathrm{g.s.}}$ process.

Another indication of ^{3}He-^{4}H clustering in ^{7}Li came from the study of the (^{3}He,^{7}Li) reactions on some $A \leq 40$ nuclei at energies around 41 MeV [6]. The measured angular distributions and excitation functions have the shapes characteristic of a direct reaction mechanism, "^{4}H transfer." For ^{19}F the (^{3}He,^{7}Be) reaction ("α transfer") was observed simultaneously with the (^{3}He,^{7}Li) reaction. It is interesting to note that the cross section for the very favored (^{3}He,^{7}Be) reaction at forward angles is only a factor of 5 larger than that for the (^{3}He,^{7}Li) reaction.

Inverse (^{7}Li,^{3}He) reactions were measured on ^{16}O at $E = 24$ MeV [7]. The angular distributions are forward peaked with the cross sections at forward angles being by a factor of 5 to 10 larger from those at 90°. The authors mention "direct transfer of four nucleons coupled to isospin $T = 1$" as an explanation of large differences in the cross sections for the ^{20}F states of the same spin but of different structure.

Some other indications of the importance of ^{4}H clustering in ^{7}Li should also be mentioned although they are not as firm as those mentioned above.

(i) Optical model analyses [8,9] of the ^{3}He elastic scattering on ^{6}Li and ^{7}Li nuclei showed that the backward part of the angular distributions cannot be described by optical model parameters similar to those for other $1p$ shell nuclei. Larger cross sections at backward angles for ^{6}Li and ^{7}Li may be due to the contributions of the ^{3}H and ^{4}H pickup by incident ^{3}He.

(ii) Three energy spectra of α particles from the ^{7}Li$(n,\alpha)tn$ reaction were measured at 0°, 15°, and 30° for $E_n = 14.6$ MeV [10,11]. A peak corresponding to the ^{7}Li$(n,\alpha)^4$H$_{\mathrm{g.s.}}$ is prominent of 0°, weak at 15°, and almost nonexistent at 30°. One of the explanations of this behavior might be an $l = 0$ ^{3}He pickup, which should be strongly forward peaked.

In conclusion, one can say that there is enough evidence for ^{4}H clustering in lithium nuclei that it should be treated on an equal footing with other observed modes. Neither its high binding energy nor the particle unstable cluster are exceptions in the clustering in light nuclei. For example, the binding energies of the ^{4}H-^{3}He and t-α modes in ^{7}Li are connected by the same factor (≈ 11) as those of the ^{3}H-^{3}He and d-α modes in ^{6}Li. The particle unstable and broad states of ^{5}He, ^{5}Li, ^{7}Li, etc. are very often used as the clusters in the cluster description of light nuclei. Obviously, it will be very hard to determine quantitatively the importance of this mode in different processes. However, in order to more thoroughly explore such a cluster structure, especially in ^{7}Li, the standard quasifree scattering technique may be the most convenient way.

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