Search for ^3n and ^4n in the reactions $^7Li + ^{11}B$

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The energy spectra of ^{14}O and ^{15}O at an angle of 8° have been measured in the reaction ^7Li (88 MeV) + ^{11}B in an effort to obtain information on the partners in the output channel of the reaction: the ^4n and ^3n systems. The energy spectra are described well by curves of the phase space for multiparticle decay in the output channel without a final-state interaction. The ^{14}O spectrum, however, has an indication of a possible formation of a quasistationary ^4n. The limits on the cross section for the production of bound ^4n and ^3n systems in this reaction are 1 and 10 nb/sr, respectively.

The possible existence of nuclear-stable and quasistationary systems of three, four, and more neutrons has been studied experimentally and theoretically in several places. The recent theoretical predictions regarding the nuclear stability of ^3n and ^4n are extremely contradictory, ranging from the total absence of resonances in these systems[1] to the possible existence of a bound trineutron.[2] In many of the experimental studies, attempts have been made to produce and detect nuclear-stable multineutron systems. Several reactions have been used to produce multineutron systems: fission reactions with thermal neutrons, fast neutrons, and deuterons,[4,3,5] a fragmentation reaction,[6,7] double charge exchange involving α clusters of heavy nuclei,[8,9] and the decay of light nuclei after the capture of a π^- meson.[10–12] Use has also been made of reactions with ^3He and ^4He (Refs. 13–16), the double charge exchange of π^- mesons with ^3He and ^4He (Refs. 17–22), and $T(\pi^-,\gamma)$ (Ref. 23) and $^4He(\gamma,2\pi^+)$ (Ref. 24) reactions. Stable multineutron systems have been observed only by Detraz[6] and Ageev *et al.*,[16] who used an activation method. Such experiments require a target of exceedingly high purity and a careful consideration of various types of background. We believe that a less ambiguous result regarding the stability of neutron nuclei can be extracted from experiments in which the energy spectrum of the conjugate product is measured. In this case, it becomes possible not only to draw conclusions about the stability of the nucleus but also to measure its mass, as has been done in studies[25,26] of the nuclei ^4H, ^5H, and ^6H. The question of the stability of multineutron systems thus requires further research. In the present paper we report a study of the ^3n and ^4n systems in the two-body reactions $^7Li(^{11}B,^{15}O)^3n$ and $^7Li(^{11}B,^{14}O)^4n$.

The experiments were carried out in a beam of 88-MeV $^{11}B^{+2}$ ions at the U-300 cyclotron. The ^7Li target, $\sim 350\,\mu g/cm^2$ thick, enriched to 99.2%, was synthesized by vacuum deposition on a thin organic substrate with a thickness $\sim 20\,\mu g/cm^2$. After deposition, the target was stored in a vacuum to prevent rapid oxidation. The reaction products were measured at an angle of $8 \pm 0.5°$ in a solid angle of 0.6 msr. The experimental apparatus is described in detail in Ref. 27. It consists of an MSP-144

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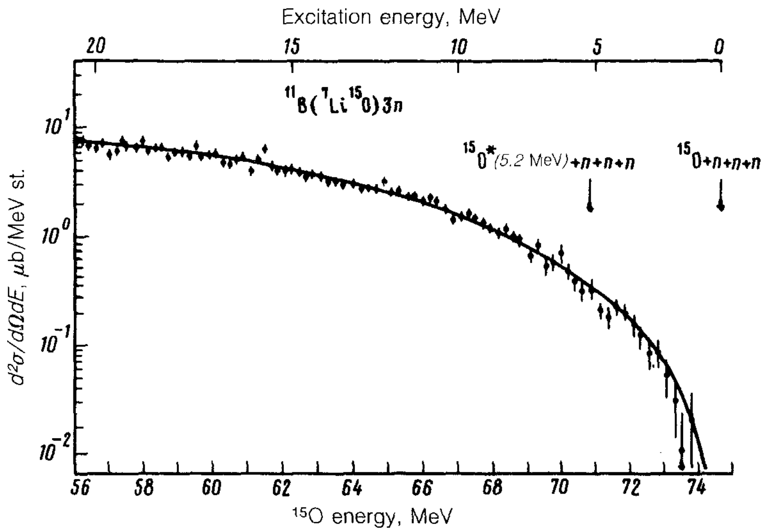

FIG. 1. The ^{15}O energy spectrum from the reaction $^{11}B(^{7}Li,^{15}O)^{3}n$. The solid line is the sum of the curves for the phase volumes of $^{15}O + n + n + n$ and $^{15}O^{*}$ (5.2 MeV) $+ n + n + n$ in the output channel of the reaction.

magnetic analyzer with an ionization chamber in its focal plane. The uncertainty in the energy measurements in this experiment, ~600 keV, is determined by the energy resolution of the beam, the target thickness, and the angular aperture of the spectrometer.

Figure 1 shows the ^{15}O energy spectrum measured over the interval 52–76 MeV for the reaction $^{7}Li(^{11}B,^{15}O)^{3}n$. The upper scale is the excitation energy in the three-neutron system (the origin for this scale is a zero binding energy, shown by the arrow in Fig. 1). The solid curve shows the results of phase-space calculations under the assumption that two reaction channels are contributing: $^{7}Li + {}^{11}B \to {}^{15}O + n + n + n$ and $^{7}Li + {}^{11}B \to {}^{15}O^{*} + n + n + n(E^{*} = 5.183$ MeV). The channels involving the formation of the ground and first excited levels of ^{15}O make contributions of 0.36 and 0.64, respectively, according to calculations by a special data-fitting program. Incorporating other channels—in particular, an attempt to group two of the three neutrons in an output channel with a zero binding energy—results in a considerably poorer agreement with the experimental points. We observe no significant deviations of any sort from the phase-space curve, with the implication that the three-neutron system does not have a quasistationary state which is populated in the given reaction. The absence of events to the right of the arrow makes it possible to determine the upper boundary for the production of a bound trineutron in this reaction: 10 nb/sr. Figure 2 shows the ^{14}O energy spectrum measured in the reaction $^{7}Li(^{11}B,^{14}O)^{4}n$. The solid curve is the calculated phase space for the five-particle decay in the output channel, $^{7}Li + {}^{11}B \to {}^{14}O + n + n + n + n$. We see that the calculations give a good description of the experimental points. Attempts to describe the experimental spectrum by means of curves of a phase-space corresponding to other reaction channels do not result in a

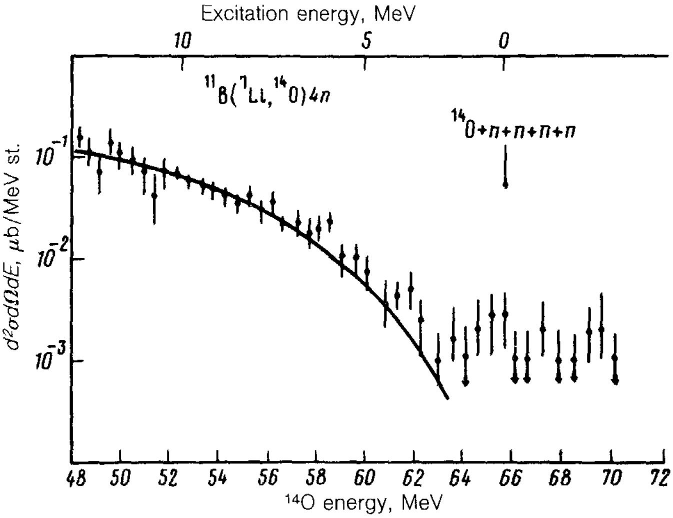

FIG. 2. The ^{14}O energy spectrum from the reaction $^{11}B(^{7}Li,^{14}O)^{4}n$. The solid line is the phase-space curve for the five-particle decay in the output channel of the reaction, $^{14}O + n + n + n + n$.

satisfactory agreement with the experimental data. The slight rises above the phase-space curve at ^{14}O energies of 58.5 and 61.5 MeV are attributed to a background of reactions involving a carbon impurity in the target: $^{12}C(^{11}B,^{14}O)^{9}Li$ and $^{12}C(^{11}B,^{14}O)^{9}Li^{*}$ ($E^{*} = 2.7$ MeV). We measured these reactions independently using a carbon target. Near a zero binding energy ($E = 65.8$ MeV); we see six events in two channels with an average background level of 0.5 event per channel. We do not rule out the possibility that these events are a background reaction involving oxygen impurities. In this case, the reactions $^{16}O(^{11}B,^{14}O)^{13}B$ should correspond to the peak at an energy $E = 65$ MeV. However, we cannot draw unambiguous conclusions regarding the nature of this peak because of the small statistical base. A definitive conclusion can be reached after a substantial improvement of the statistical base and by choosing a reaction in which the peaks corresponding to a zero binding energy of the neutrons in the four-neutron system and to the background reaction involving oxygen are separated along the energy scale by at least 1.5 MeV. To the right of the arrow corresponding to a zero binding energy of the neutrons in the ^{4}n system we see several events, which are attributed to the experimental background, due primarily to the buildup of pulses in the ionization chamber. It corresponds to a cross section ~ 1 nb/sr.

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