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States of ^{12}N with enhanced radii

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Recently the evidence of the excited states of light nuclei with enlarged radii, located close to and above the particle emission threshold, was convincingly demonstrated (see, e.g., [1] and references therein). The existence of neutron halos in the short-lived excited states of some stable and radioactive nuclei was revealed, in particular, by the asymptotic normalization coefficient (ANC) analysis of the neutron-transfer reactions [2, 3].

The ANC analysis of the ^{11}B(d,p)^{12}B reaction at $E_{\rm lab} = 21.5$ MeV was carried out in our group [4]. Radii of the valence neutron for the first five excited states of ^{12}B were determined. Calculations showed that the rms radii of the last neutron in the second 2^-(1.67 MeV) and the third 1^-(2.62 MeV) excited states of ^{12}B far exceed those for the ground state (g.s.) and the first 2^+(0.95 MeV) excited state. Moreover, a probability of the last neutron to be outside the range of the interaction radius, so-called D_1 coefficient, was obtained to be 53 and 62 %, respectively. It should be noted that a formal criterion of a halo state is that D_1 should be more than 50 % and it is fulfilled in both cases.

Accordingly to charge independence of nuclear forces, mirror nuclei are isobars that have proton and neutron numbers interchanged. Some states of mirror nuclei with the same quantum numbers (isospin, spin/parity), isobaric analogue states (IAS), can form the isospin or isotopic multiplets (doublets, triplets, etc.) and then approximately have the same structure and radii.

Natural question arises: what we can expect in the IAS of ^{12}B in the mirror ^{12}N nucleus? The IAS that presumable have halos are determined in a more complicated manner: replacing the neutron in the halo state with a proton does not necessarily lead to the appearance of a similar proton structure. The fact is that the appearance of a halo is determined by the proximity of the valence nucleon to the emission threshold, and it can be very different for a neutron and a proton. One notable example is the IAS of mirror ^{13}C and ^{13}N nuclei. ^{13}C in the $1/2^+$, 3.09-MeV state has a neutron halo [2, 3] that satisfies all halo criterions. The $1/2^+$, 2.37-MeV IAS in ^{13}N does not lie in the discrete spectrum, but in the continuum spectrum, and therefore the proton wave function differs from the neutron one. An increase of the ^{13}N radius in this state is also observed [5].

Now we study excited states of ^{12}N, namely the 2^+(0.96 MeV), 2^-(1.19 MeV), and 1^-(1.80 MeV) states of ^{12}N. We propose to use the Modified Diffraction Model (MDM) method [5–7] and apply it to analyze the (^{3}He,t) reaction data. Obtained radii for ^{12}N in the 2^- and 1^- states will be compared with those received for the excited states of ^{12}B [4]. The problem is that existing data are not completed enough to make definite conclusion about the radii of the 2^- and 1^- states in ^{12}N. The existing in the literature data are presented only at three energies: 36 [8], 49.8 [9], and 81 MeV [10]. The data at 36 MeV contain only the angular distributions for the g.s. and the 0.96-MeV states. The data at 49.8 MeV contain the angular distributions for the g.s., 0.96-MeV, and 1.20-MeV states. The data at 81 MeV contain all interested for us states, but they present only one indinstinct oscillation in the angular distributions. The angular distribution for the 0.96-MeV state obtained at 81 MeV [10] is not comparable with others, if it would

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be drawn as a function of linear transferred momentum. This fact stimulate us to carried out a new experiment on the ^{12}C(^{3}He,t)^{12}N reaction at $E(^3\text{He}) = 40$ MeV.

The measurements were conducted at the University of Jyväskylä (Finland) using the K130 cyclotron [11] to produce a ^{3}He beam at $E(^3\text{He}) = 40$ MeV. The 150 cm diameter Large Scattering Chamber was equipped with four $\Delta E{-}E$ detector telescopes, each containing two independent ΔE detectors and one common E detector. So each device allowed carrying out measurements at two angles. The measurements in c.m. angular range 10° were conducted in one exposure. The differential cross sections of the ^{12}C(^{3}He,t)^{12}N reaction were measured in the c.m. angular range of 8°–69°. Self-supported ^{12}C foils of 0.23 and 0.5 mg/cm^2 thicknesses were used as targets. The beam intensity was about 20 particle nA.

Triton angular distributions for the g.s. and three first excited states of ^{12}N: 0.96-MeV 2^+, 1.19-MeV 2^-, and 1.80-MeV 1^- were measured. The resulting differential cross sections for the ^{12}C(^{3}He,t)^{12}N reaction with DWBA calculations are presented in Fig. 1.

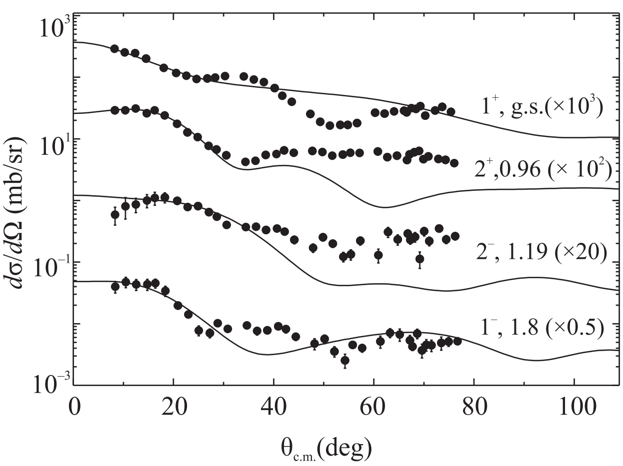

Fig. 1. Triton angular distributions from the ^{12}C(^{3}He,t)^{12}N reaction at E(^{3}He) = 40 MeV populated the 1^+(g.s), 2^+(0.96 MeV), 2^-(1.19 MeV), and 1^-(1.80 MeV) states of ^{12}N. The curves correspond to the DWBA calculations

Let us discuss the results of the MDM analysis of the existing and our new data on the ^{12}C(^{3}He,t)^{12}N reaction at 40 MeV.

We try to make estimations of *rms* radius of the g.s of ^{12}N and got value: 2.8 ± 0.4 fm, which is consistent with the estimates resulting from our DWBA analysis – 2.9 fm.

Also the *rms* radii for the 1.19 MeV and 1.80 MeV states were determined using MDM. The 1.19 MeV state is excited by transfer of two angular momentums $L = 0$ and $L = 2$ and complicates analysis a bit. An average value was found to be 2.8 ± 0.3 fm. The *rms* radius for the 1.80 MeV state is 3.0 ± 0.1 fm. These values are larger than *rms* radius of the g.s. of ^{12}N 2.47 ± 0.07 fm [12].

The diffraction and *rms* radii of ^{12}C in the IAS were determined by the MDM from the inelastic $^3\text{He} + {}^{12}\text{C}$ scattering [9]. Within the error bars, the *rms* radii of ^{12}C in the 15.11-MeV 1^+ and the 16.57-MeV 2^- states agree with the *rms* radii of their IAS in ^{12}N. The preliminary ANC analysis in which excited states of ^{12}C are considered as a weakly bounded (effective positive energy of a valence proton, $\varepsilon \approx 0.01$ MeV), gives approximately the same radii. Moreover, D_1 coefficient for the 2^- state is more than 50 %, which indicate that the 16.57-MeV 2^- state of ^{12}C can be considered as a proton halo-like state. Complete results of the ANC analysis will be published later.

Finally, we revealed that ^{12}B, ^{12}N, and ^{12}C in the IAS with $T = 1$, and spin-parities 2^- and 1^- have increased radii and exhibit properties of neutron and proton halo states.

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