Development of alpha cluster structure in nuclei of the same mass number

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Abstract. The resonant ^{14}N+α particle scattering was studied in the ^{18}F excitation region from 6.5 to 9 MeV at Astana cyclotron using the TTIK approach. The excitation functions for the elastic ^{14}N+α scattering were analyzed in the framework of R-matrix approach. The observed strong alpha cluster structure in ^{18}F is compared with that in ^{18}O.

This paper summarizes the results of nuclear structure studies conducted using resonant reactions and the Thick Target Inverse Kinematic (TTIK) technique at the Astana cyclotron. In TTIK, inverse kinematics are employed, allowing incoming ions to be slowed down in an extended gas target of helium or hydrogen. As α particles and protons have lower energy losses than the beam ions, they are detected from the scattering event while the beam ions stop within the gas. The recoiling light particles are detected in a Si detector array positioned at forward angles. TTIK offers the advantage of continuous excitation function measurements using a single beam energy, enabled by the beam's deceleration within the gas target. Zero-degree measurements correspond to 180 degrees in the center-of-mass system, where the method achieves its optimal energy resolution. This approach provides for readily observation of excitation function for the interaction of ^{4}He with rare gas isotopes like ^{15}N, ^{17,18}O [2-4]. The development of rare beam facilities opens a possibility for a comparison of resonance structure in mirror reactions. It is well known that the interaction of radioactive nuclei with hydrogen and helium plays an important role in astrophysics [5]. While low intensity of rare beams is an evident obstacle to obtain the detailed information on this interaction, the data on the mirror processes can be very helpful [4,5]. Additionally, the comparison in question has demonstrated a surprising energy shift of strong alpha cluster states in mirror nuclei [5].

Recently we have made measurements of excitation functions for the ^{14}N (T=0)+α elastic scattering, and the results can be compared with the available data on ^{14}C (T=1)+α interaction [6].

A 24.5 MeV beam of ^{14}N entered the scattering chamber filled with helium through 2 micron titanium foil. We identified different processes, the results of ^{14}N interaction with ^{4}He by combining the TTIK and Time-of-Flight (ToF) methods [7].

We used a multilevel, multichannel R-matrix code, AZURE [8], to analyze the excitation functions for the elastic ^{14}N+α scattering obtained for excitation energies in the range 6.5-9 MeV and angular region 138°-180°. An example of the experimental excitation function and the R-matrix fit at 180° in center-of-mass system is shown in Fig.1. Very strong resonances are observed in the ^{18}F excitation region of 7.2-8.5 MeV with large reduced alpha particle width. Recent work [9] also indicates large reduced alpha cluster widths, while some spin assignments differ.

Our analysis shows that the sum of the α particle reduced widths for *l*=3 states (2^-, 3^-, 4^-) is 1.17 and for *l*=4 (3^+, 4^+, 5^+) is 2.43. According to extreme alpha cluster considerations the reduced width should be equal to 1 for each spin value in these groups, because of 1^+ spin of ^{14}N states. So, the "averaged" clusterization is 0.39 for *l*=3 and 0.81 for *l*=4. Of course, it is interesting to compare this result with detailed experimental data of [10] and [6] on the cluster structure in ^{18}O (T=1). One should expect that in the nuclei of the same atomic number the corresponding alpha cluster states with a similar structure should be observed at close excitation energies; the lowest energies should be in the nucleus with the lowest isospin. This is expected because (a) high shell model configurations should contribute to strong alpha cluster states, and (b) more states are available in nuclei with the lowest isospin. M.L. Avila

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et al. [6] observed two 3$^-$ levels at excitation energies of 8.29 and 9.35 MeV in ^{18}O, with a combined reduced alpha cluster width in agreement with our results for ^{18}F.

However, no strong alpha cluster 4$^+$ states were found in Ref. [6] up to excitation energy of 14 MeV in ^{18}O. The strongest one [6] could be at 8.96 MeV (2$^+$, 3$^-$,4$^+$). If it is a 4$^+$ state, then the reduced width will be 0.2. It is worthwhile to note, that P. Descouvernont and D. Baye [11] in the study of α+^{14}C molecular states indicated that the reduced width of 3$^-$ (8.29 MeV) state should be large and predicted a very high reduced width (0.82) for the 4$^+$ state at 10.26 MeV in ^{18}O. Therefore, the observed difference of *l*=4 alpha cluster strength in A=18 nuclei seems interesting and deserves additional studies.

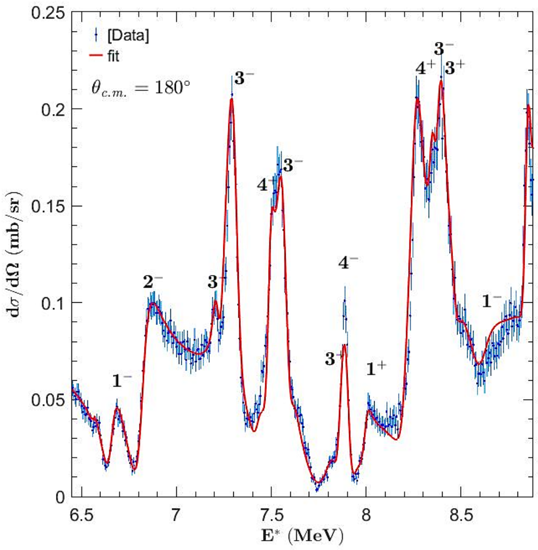

Fig. 1. R-matrix fit for the excitation functions for α + ^{14}N elastic scattering.

We performed an R-matrix analysis of the reactions ^{4}He(^{14}N,α) up to the excitation energy of 9.0 MeV in ^{18}F. The parameters for 23 resonances were defined. The analysis of the reduced widths of alpha cluster states in A=18 nuclei, ^{18}F and ^{18}O, indicates a surprising differences in the alpha cluster structure in these nuclei. We believe that a future development of the studies on the cluster structure in nuclei with the same A number can bring important nuclear structure data.

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