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States of ^{13}C with abnormal radii

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Abstract

Differential cross-sections of the elastic and inelastic ^{13}C + α scattering were measured at $E(\alpha) = 90$ MeV. The root mean-square radii ($< R_{rms} >$) of ^{13}C nucleus in the states: 8.86 ($1/2^-$), 3.09 ($1/2^+$) and 9.90 ($3/2^-$) MeV were determined by the Modified diffraction model (MDM). The radii of the first two levels are enhanced compared to that of the ground state of ^{13}C, confirming the suggestion that the 8.86 MeV state is an analogue of the Hoyle state in ^{12}C and the 3.09 MeV state has a neutron halo. Some indications to the abnormally small size of the 9.90 MeV state were obtained.

1 Introduction

During recent years evidence of the existence of nuclear excited states with abnormally large radii was obtained. In our previous experiment on the

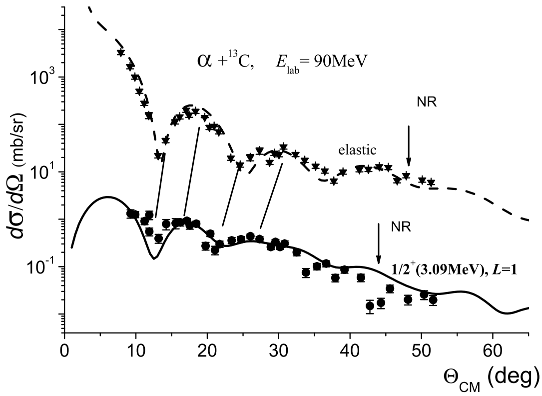

Figure 1: Differential cross sections of the ^{13}C + α elastic scattering and inelastic one leading to the 3.09 MeV state in ^{13}C at $E(\alpha) = 90$ MeV. Results of the optical model calculations are shown by the dashed curve. The solid curve corresponds to the DWBA calculations ($L = 1$). The positions of the rainbow minima are denoted by the vertical arrows.

inelastic scattering ^{13}C $(\alpha, \alpha^{'})$ at $E(\alpha) = 65$ MeV [1] we observed three excited states whose radii differed from that of the ground state: 3.09 MeV $(1/2^{+})$, 8.86 MeV $(1/2^{-})$ and 9.90 MeV $(3/2^{-})$. Because of importance of the obtained result new measurements of the inelastic scattering were performed at $E(\alpha)$=90 MeV.

2 Results and discussion

Differential cross sections of the elastic and inelastic ^{13}C + α scattering were measured at the Jyvaskyla University cyclotron, Finland. The data for elastic scattering and inelastic one leading to the 3.09 MeV state are presented in Figure 1. The extremes (joined by the straight lines) should be out of phase if the elastic and inelastic diffraction radii are equal. The observed shift of the extremes of the inelastic scattering cross section to smaller angles indicates the enhancement of the radius for the 3.09 MeV state in comparison with the ground state one. Evaluation of the radius was performed by three independent methods: Modified diffraction model (MDM) [2], Nuclear rainbow method (NRM) [3, 4] and method using the asymptotic normalization coefficients (ANC) [5, 6]. All three approaches gave similar values verifying the validity of the used methods (Table 1) and confirm existence of neutron halo in this states [1, 5].

Differential cross-sections of the inelastic ^{13}C + α scattering leading to the 8.86 MeV state at $E(\alpha) = 90$ and 65 MeV are shown in Figure 2. Observed identity of the forward angles (up to 45 deg) structure confirms the diffraction origin of the oscillations and similarity of the diffraction radii measured at different energies. The minima at $q \approx 2.5$ fm^{-1} in 65 MeV data and $q \approx 2.0$ fm^{-1} in 90 MeV data were identified as the rainbow (Airy) one. Application of MDM and NRM to the 8.86 MeV state showed that the latter also has an enhanced radius (Table 1) close to that of the Hoyle state (7.65 MeV, 0^+) of ^{12}C [2].

Table 1: $< R_{rms} >$ for the different states in ^{13}C nucleus.

E^*, MeV, J^π	0.00, $1/2^-$	3.09, $1/2^+$	8.86, $1/2^-$	9.90, $3/2^-$
Table data	2.33			
MDM, 65MeV		2.98±0.09 *	2.68±0.12 [1]	2.02±0.14 [1]
NRM, 65MeV		⩾ 2.7 [1]	⩾ 2.5*	
ANC,65MeV		2.62±0.10 [5] 2.72±0.02 [6] 2.68 [7], theory		
MDM,90MeV		2.88±0.19*	2.63±0.16*	1.76±0.23 [8]
NRM,90MeV		⩾ 2.6*	⩾ 2.5*	
Structure	Shell model	Neutron halo	Dilute cluster	Compact cluster

* this work

Estimates done by MDM method gave the value of the radius of the 9.90 MeV state which is less than that of the ground state (Table 1). This conclusion is confirmed by comparison of different inelastic scattering cross-sections with angular momentum transfer $L = 2$ (Figure 3). Diffraction structure of the cross-section for the 9.90 MeV state is shifted to the larger angles indicating its smaller radius. This result contradicts to the predictions [9] according to which the 9.90 MeV state should have the radius comparable with that of the Hoyle state. Physical reason of such reduction of the nucleus size is not clear.

Thus, diluted states at 3.09 and 8.86 MeV and a compact one at 9.90 MeV co-exist in ^{13}C together with a number of states with normal radii.

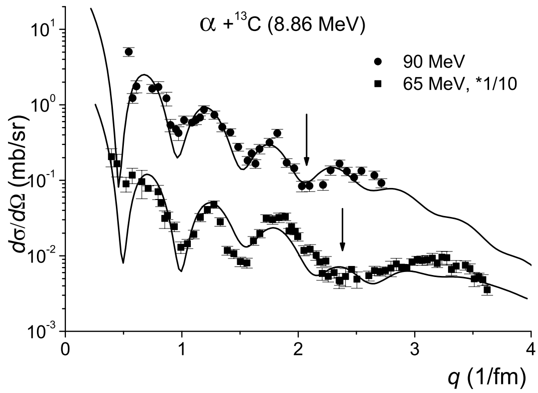

Figure 2: Differential cross-sections of the inelastic ^{13}C + α scattering leading to the 8.86 MeV state at 90 and 65 MeV as a function of the linear momentum transfer q. The positions of the rainbow minima are denoted by arrows.

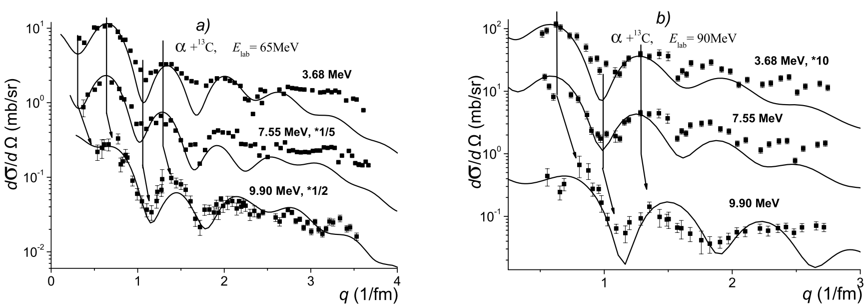

Figure 3: Differential cross sections of the inelastic $^{13}\mathrm{C}(\alpha,\alpha)^{13}\mathrm{C}^*$ scattering corresponding to $L = 2$ transfer for the states of ^{13}C nucleus: 3.68 MeV, 7.55 MeV and 9.9 MeV as a function of the linear momentum transfer q. Vertical lines are drawn through the extremes of the differential cross sections for the 3.68 and 7.55 MeV. The corresponding extremes of the cross sections for the 9.9 MeV state are denoted by arrows. Solid curves correspond to the DWBA calculations ($L = 2$). The figure was taken from the publication [8].

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