Investigation of α-particle scattering from 13C at 29 MeV

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Abstract: We have measured the angular distributions for the elastic and inelastic scattering of α-particles from 13C in the isochronous cyclotron U-150M INP (Almaty, Kazakhstan). The experimental results were analyzed within the framework of both the optical model using different complex potentials and the double folding potential obtained with different density-dependent nucleon-nucleon interactions.

1. Introduction
Neutron-halo nuclei discovered in 1985 by Tanihata et al. [1,2] are exotic systems consisting of a tightly bound core surrounded by a diffuse nuclear cloud. These systems were found in the ground states (g.s.) of some light, neutron-rich radioactive nuclei located close to the neutron dripline. Until now neutron halo was observed almost exclusively in the ground states of some radioactive nuclei. In the framework of the hypothesis of the α-partial condensation, some excited states of 13C may have larger values of the radius.

13C is a good example of a “normal” nucleus well described by the shell model. Its level scheme is reliably determined up to the excitation energies ~ 10 MeV [3]. Analysis [4] of the 13C + α scattering data measured at E(α) = 388 MeV [5] really demonstrated a considerable enhancement of the radius at this particular energy. Consequently, new measurements especially at lower energies are highly desirable.

In the current work we continue the investigation of the nature of 13C excited states at low energies.

2. Experimental Details
The experiment was carried out at the isochronous cyclotron U-150M in Institute of Nuclear Physics (Almaty, Kazakhstan) at energy E(α)=29 MeV. Sets of E-ΔE telescopes for detection of the alpha-particles were used in the experiments. A self-supporting 13C target (0.4 mg/cm²) with 90% enrichment was used. It contained some impurities of 12C and 16O.

The (E-ΔE) telescopes of silicon semiconductor detectors, which cover the scattering angles of 10–80°, were used in data acquisition. For optimal focusing of the accelerated ions beam on the target, two collimators of diameter 2 and 3 mm were used. The (E-ΔE) method was used in the recording and identification of the reaction products.

3. Results and discussion:
The theoretical calculations for the elastic scattering of α-particles from 13C target at energies 29, 48.7, 54.1 and 65 MeV were performed within the framework of the code Fresco [6] using two different potentials: phenomenological optical potential and semi-microscopic double folding potential. The
comparison between the experimental data and the theoretical predictions for $^4$He($\alpha$,\alpha) $^4$He at the aforementioned energies is shown in figure 1 using the potential parameters listed in table 1. The table 1 shows: depth ($V_0$, $W$), radii ($r_\text{v}$, $r_\text{w}$) and diffuseness ($a_\text{v}$, $a_\text{w}$) of the real and imaginary part of the potential, respectively and the normalization coefficient ($N_r$), that was used for the calculations in the folding model. Coulomb radius is $r_\text{c}=1.28$ fm.

In the Optical Model (OM) calculations at energies 48.7, 54.1 [7] and 65 MeV [8] we used two different potential sets (A and B), which are a combination of real volume part plus imaginary volume part. The potential set A was used to reproduce the experimental data in the forward hemisphere with the fixed values of radii $r_\text{v}=1.112$ fm and $r_\text{w}=1.6$ fm of real and imaginary part, respectively; the potential set B was used to reproduce the experimental data in the full angular range using the same fixed values for the parameters $r_\text{v}$ and $r_\text{w}$ as in set A.

Table 1: The optimal potential parameters obtained for elastic scattering of $\alpha$-particles from $^{13}\text{C}$ at different energies.

| E MeV | Potential set | $V_0$ MeV | $r_\text{v}$ fm | $a_\text{v}$ fm | $N_r$ | $W$ MeV | $r_\text{w}$ fm | $a_\text{w}$ fm | $r_\text{c}$ fm |
|-------|---------------|------------|-----------------|-----------------|------|---------|-----------------|-----------------|----------------|
| 29    | OM A          | 147.22     | 1.112           | 0.736           | 1.6  | 0.267   | 1.28            |                 |                |
|       | OM B          | 142.23     | 1.245           | 0.762           | 1.6  | 0.731   | 1.28            |                 |                |
|       | DF A          |            |                 | 0.97            | 1.6  | 0.267   | 1.28            |                 |                |
| 48.7  | OM A          | 134.49     | 1.112           | 0.79            | 1.6  | 0.639   | 1.28            |                 |                |
|       | OM B          | 120.38     | 1.245           | 0.73            | 1.6  | 0.639   | 1.28            |                 |                |
|       | DF A          |            |                 | 0.97            | 1.6  | 0.639   | 1.28            |                 |                |
| 54.1  | OM A          | 129.48     | 1.112           | 0.795           | 1.6  | 0.8     | 1.28            |                 |                |
|       | OM B          | 117.57     | 1.245           | 0.753           | 1.6  | 0.76    | 1.28            |                 |                |
|       | DF A          |            |                 | 0.96            | 1.6  | 0.8     | 1.28            |                 |                |
| 65    | OM A          | 123.07     | 1.112           | 0.8             | 1.6  | 0.76    | 1.28            |                 |                |
|       | OM B          | 119.49     | 1.245           | 0.784           | 1.6  | 0.728   | 1.28            |                 |                |
|       | DF A          |            |                 | 0.98            | 1.6  | 0.76    | 1.28            |                 |                |

In the double folding (DF) calculations, the real part of the potential was derived by folding the density distributions of the target nucleus and the projectile with the nucleon-nucleon interaction potential. In potential DF at energies 29 and 65 MeV, the normalization coefficient for the real part of the potential equals 0.97 and 0.98 respectively and the phenomenological imaginary volume parameters were fixed to the same values used in potential set A for OM calculations. At energies 48.7 and 54.1 MeV the normalization coefficient for the real part of the potential equals 0.97 and 0.96 respectively.
Figure 1. Comparison between the experimental data and the calculated differential cross section for elastic scattering of $\alpha$-particles from $^{13}$C at energies 29, 48.7, 54.1 and 65 MeV using both OM (set A and set B) and DF potentials.

4. Summary

Analysis of data on elastic scattering at energies 29 MeV, together with published data at energies of 65 MeV, 54.1 and 48.7 MeV was carried out within the framework of optical model with the phenomenological optical potentials parameters and semi-microscopic potentials calculated within the framework of double-folding model. Physically reasonable parameters of interaction potentials were obtained in fitting experimental data in a wide energy range of incident particles. The energy dependence of the depth of the real part of the potential was determined.

Analysis of data on inelastic scattering is planned to done with the use of the obtained parameters of optical potentials in the following papers.

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