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Alpha cluster transfer in the elastic scattering of ^{13}C ions on ^{9}Be nuclei

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Abstract. The angular distribution of the elastic scattering of ^{13}C ions on ^{9}Be nuclei was measured at E_{lab} = 22.75 MeV at the DC-60 accelerator in the Institute of Nuclear Physics (Astana, Kazakhstan). The analysis showed that the optical model does not provide the cross sections enhancement in the backward angular direction. This increase could be explained by the contribution of the α-cluster transfer mechanism. The data analysis was performed in the framework of the coupled reaction channels method. The optimal parameters of the potential were obtained.

Key words. The elastic scattering, the optical model of the nuclei, the alpha-cluster transfer mechanism, the coupled reaction channels calculation.

1. Introduction

In the scattering of the particles on 1p-shell nuclei, having the cluster structure, one can see the anomaly increasing of the cross section at large angles. Most often, this increase is connected with the transfer mechanism of the clusters or nucleons. This behavior of the cross sections has been observed by Jarczyk et al. (1998) in the elastic scattering of ^{9}Be on ^{13}C and by Bodek et al. (1980)in the scattering of ^{13}C on ^{9}Be at the energies of 11- 15 MeV in the center of mass system. The alpha-cluster transfer contribution to the ^{9}Be+^{13}C scattering at higher energy (50.46 MeV) was investigated by Barbadoro et al. (1990). In another paper (Peterson et al. 1982), the significant rise of the scattering cross section of the α - particle on ^{9}Be nuclei can be reproduced using the optical potential with deep real part without taking into account the possible contribution of the elastic transfer of the α-cluster. The rise of the cross sections at the backward angles is typical for the alpha-cluster structured nuclei (Burtebayev et al. 2011). In this work the elastic scattering of ^{13}C ions on ^{9}Be nuclei was measured at E_{lab} = 22.75 MeV.

2. Experimental details

The angular distribution for the elastic scattering of ^{13}C ions on ^{9}Be nuclei was measured at E_{lab} = 22.75 MeV at the DC-60 accelerator in the Institute of Nuclear Physics (Astana, Kazakhstan). A ^{9}Be target with the thickness of 30 g cm^{-2} was bombarded with a ^{13}C beam at the energy E_{lab} = 22.75 MeV. The reactions products were detected by two ΔE-E telescopes consisting of the two semiconductor silicon surface-barrier detectors with the thicknesses of 9μ (ΔE) and 500μ (E). The measurements of the angular distributions were performed in the angular range 80^o-70^o with 2^o steps in the laboratory system. The absolute values of the cross sections were determined by the normalization to the ^{13}C elastic scattering at the small angles to the data which is known from the earlier experiments (Jarczyk et al. 1998). The absolute cross sections are believed to have the accuracy within 10%. The typical energy spectra of the detected particles are shown in Fig. 1.

3. Data analysis

The most developed method of extracting information about the potentials of the interaction of the particles with the atomic nuclei is the phenomenological analysis of the experimental data on the elastic scattering, which is based on the optical model. The optical model takes into account the effect of the inelastic channels by the phenomenological introduction of the absorbing imaginary part of the potential between the colliding nuclei. In this approach, the problem of the scattering in a many-particle system is reduced to a simple process of the scattering in the field of the complex optical potential U(r). The shape and the size of this potential are determined by the optimizing of their parameters when describing the corresponding experimental data. Technically, this procedure is associated with the solution of the Schrodinger equation:

$$\Delta\Psi + \frac{2}{\mu}[E + U(r)]\Psi = 0 \qquad (1)$$

Here μ = m A_p* A_t/(A_p + A_t) - the reduced mass of the colliding nuclei; A_p , A_t - the masses of the projectile and the target nucleus; m - the mass of a nucleon; E - kinetic energy of the relative motion in the c. m. s.

Usually, the calculations are limited by the central potentials which depend only on the distance between the mass centers of the colliding nuclei. This is justified by the fact that the detailed theoretical study of the spin-orbit interaction has virtually no influence on the differential cross section of the elastic scattering in the forward angular hemisphere. Thus, the optical potential can be written as:

$$U(r) = V_C(r) - V(r) - i(W_V(r) + W_S(r)) \qquad (2)$$

The first term is the Coulomb potential. Since the scattering is not sensitive to the particular form of the charge distribution, there is no need to consider its diffuse edge. For the practical purposes it is sufficient to take the Coulomb potential as uniformly charged sphere in the form of:

$$V_C(r) = \frac{Z_p Z_t e^2}{r} \rightarrow r \leq R_C \qquad (3)$$

where R_C= r_C* $A_t$$^{1/3}$ - the Coulomb radius; Z_p and Z_t - the charge of the incident particle and the target nucleus.

The other terms in the formula (2) describe the nuclear potential usually taken in a Woods-Saxon form with the set of the phenomenological parameters which give the best agreement with the experiment. The Woods-Saxon form factor was used for both the real and imaginary parts:

$$U(r) = V + iW \qquad (4)$$

$$V = V_0[1 + exp(r - R_r)/a_r]^{-1} \qquad (5)$$

$$W = W_0[1 + exp(r - R_i)/a_i]^{-1} \qquad (6)$$

V_0 , W_0, a_r , a_i, R_r and R_i being the depth, diffuseness and radii of the real and

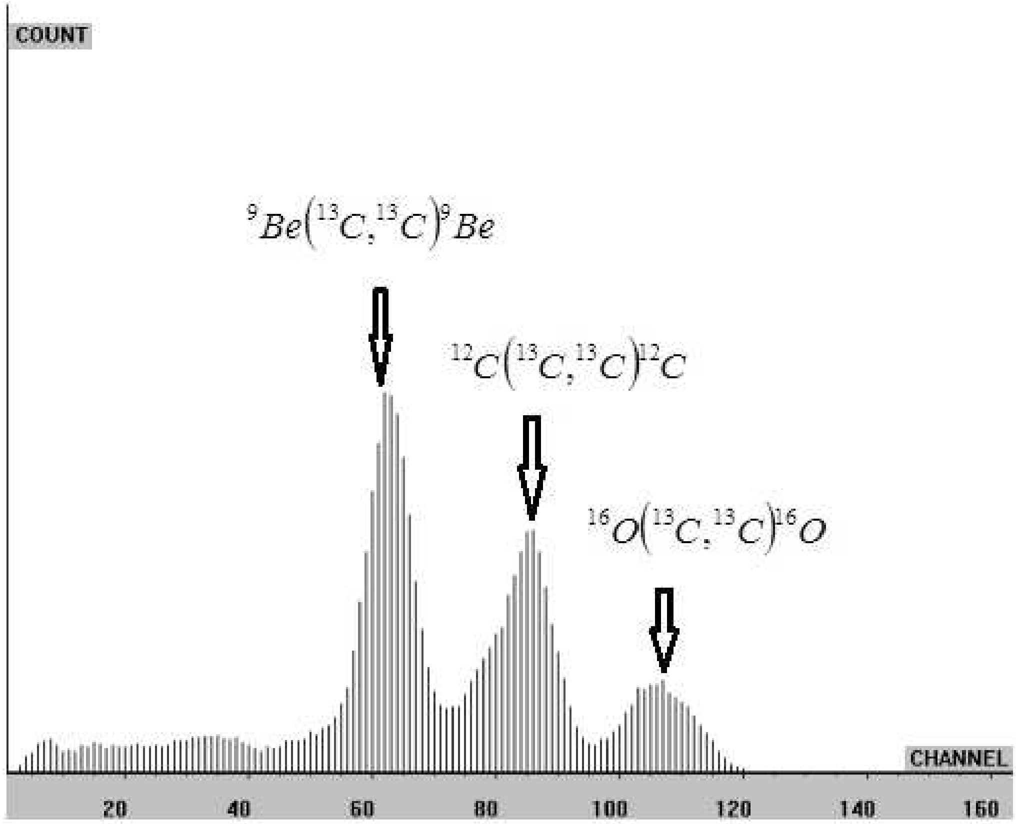

Fig. 1. The energy spectrum of the scattered ^{13}C ions on ^{9}Be, ^{12}C, ^{16}O nuclei

Table 1. Potential parameters

E (MeV)	V_0 (MeV)	R_v (fm)	a_r (fm)	W_0 (MeV)	R_i (fm)	a_i (fm)	SF
22.75	60	1.193	0.6	32.6	1.193	0.6	0.92

imaginary potentials, respectively. The radii are expressed in terms of the mass numbers A_p and A_t of the nuclei involved given by:

$$R = r_0(A_p^{1/3} + A_t^{1/3}) \quad (7)$$

The parameters of the optical potential (OP) were selected to achieve the best agreement between the theoretical and the experimental angular distributions (see Table 1). The OM description of the experimental data is shown in Fig. 2 by the dashed line. It can be seen that OM well describes the differential cross sections of the elastic scattering in the forward hemisphere. However, this model does not reproduce the behavior of the experimental cross sections at the angular range 100 ^{o} - 165^{o} and does not predict the rise of the cross sections at large angles. This increase could be interpreted to be due to the contribution of the α-cluster transfer. Only accounting for the α-transfer mechanism allows de-

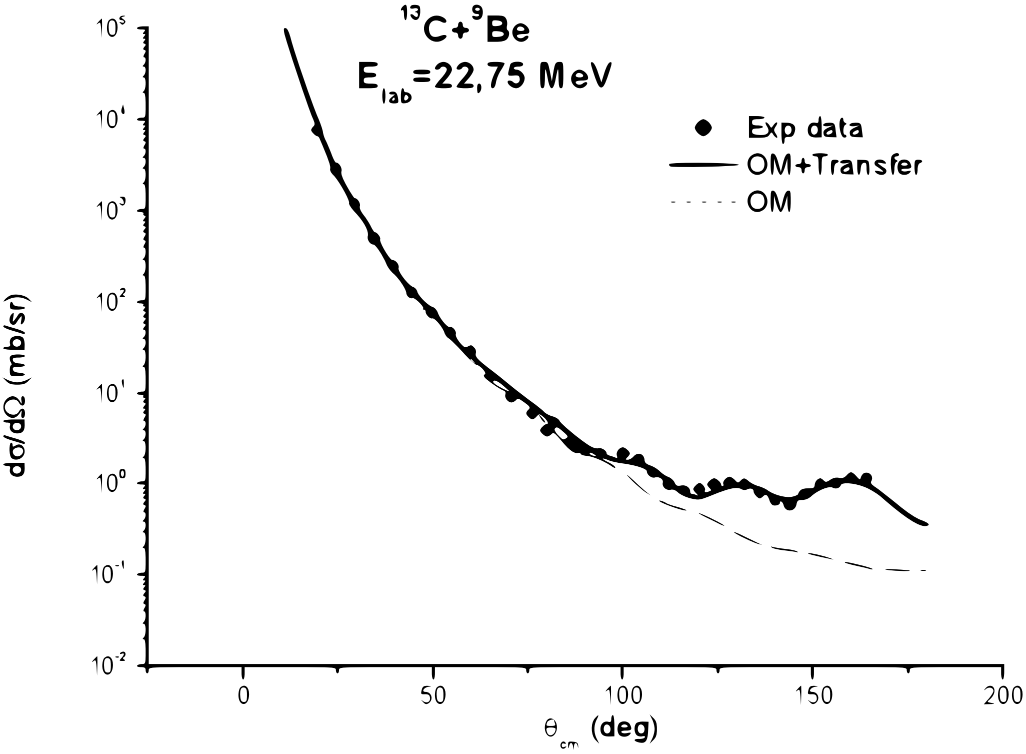

Fig. 2. The angular distribution of the elastic scattering of ^{13}C on ^{9}Be at the E_{lab}=22.75 MeV. Circles are experimental data; the dashed line is the optical model prediction, and the solid line represents the coupled reaction channels calculation by code FRESCO with taking into account the α-cluster exchange mechanism

scribing the cross sections rise at large angles. This is done by the coupled reactions channels calculations (Peterson et al. 1982) using code FRESCO. The result of the calculation is shown in Fig. 2 by the solid line. The spectroscopic factor S = 0.92 for ^{13}C to ^{9}Be $+\alpha$ was extracted from the present analysis. It can be seen from Fig. 2 that the coupled reaction channels calculation by taking into account the elastic α-particle transfer reproduces the character of the cross sections in the full angular range.

4. Conclusions

The rise of the cross sections at the backward angles was observed in the elastic scattering of ^{13}C on ^{9}Be at the E_{lab}=22.75 MeV which is typical for the alpha-cluster structured nuclei. The analysis showed that the optical model does not provide the cross sections enhancement in the backward angular direction. The data analysis was also performed in the framework of the coupled reaction channels method. These calculations showed that the increase of the cross sections at large angles can be interpreted by the contribution of the α-cluster transfer. The optimal parameters of the potential were obtained. The work performed under the grant number 2272 / GF4 MES RK.

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