Proc. 14th Int. Symp. on Nuclei in the Cosmos (NIC2016)
JPS Conf. Proc. **14**, 021016 (2017)
https://doi.org/10.7566/JPSCP.14.021016

Measurements of the Elastic and Inelastic Scattering Cross Sections of ^{13}C Ions on ^{12}C Nuclei at the Near Coulomb Barrier Energy

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(Received July 27, 2016)

Differential cross sections for elastic scattering of ^{13}C ions on the nuclei ^{12}C were measured using extracted beam from the cyclotron K=160 HIL (Warsaw University) in wide range of angles at energy 2.5 MeV/nucleon. The angular distribution showed almost monotonic decrease of the cross sections at forward hemisphere. An increase in differential cross section starting from intermediate angles is predicted by coupled channels calculations.

KEYWORDS: optical model parameters, differential cross sections, neutron transfer reaction mechanism, rise of the cross section.

1. Introduction

For the ^{12}C + ^{13}C system the neutron transfer mechanism $^{12}C(^{13}C, ^{12}C)^{13}C$ can manifest at backward angles in the scattering. In this context, study of the cross sections in this area is of great interest for astrophysics since it allows us to estimate cross sections of the possible radiative capture $^{12}C(n, \gamma)^{13}C$ reaction and its role in the evolution of the Universe immediately after the Big-Bang. Some of the key reactions for the carbon and oxygen burning stages are $^{12}C+^{12}C$ [1], $^{12}C+^{16}O$ [2, 3] and $^{16}O+^{20}Ne$ [4] leading to a synthesis of more heavy nuclei. From the angular distribution of the experimental data the spectroscopic factor can be extracted for the $^{13}C \rightarrow {}^{12}C$ + n vertex which is valuable for the $^{12}C(n, \gamma)^{13}C$ reaction. Previously elastic scattering ^{12}C + ^{13}C at an energy close to our was investigated in limited range of angles up to 60^0 [5]. Scattering in this system has been also investigated by Chua et al. [6, 7] in the energy range from E_{lab}=20 to 35.5 MeV. Their calculations do not predict the cross section rise at larger angles where the neutron exchange mechanism can be dominant.

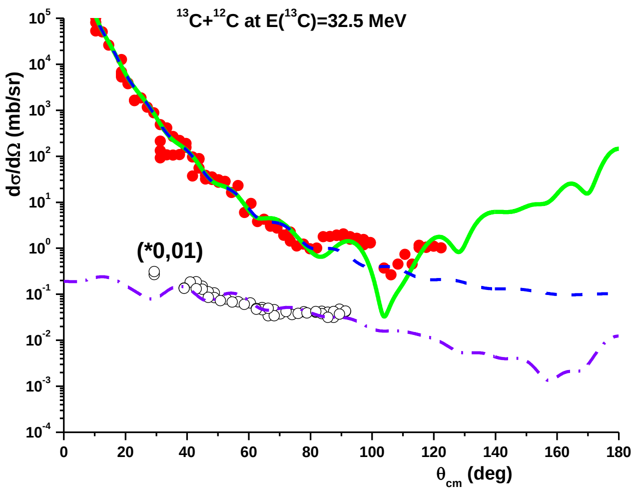
2. Experimental setup and data analysis

In the present work angular distributions of elastic and inelastic scattering of ^{13}C ions by ^{12}C nuclei were measured using beam with the energy of 2.5 MeV/nucleon extracted from the Heavy Ion Laboratory Cyclotron (K = 160) of the Warsaw University. The charged particles were detected and identified by four ΔE-E counter telescopes installed in the ICARE scattering chamber. The overall energy resolution was about 700 keV. The telescopes consisted of the ionization chamber as ΔE detector and the semiconductor silicon detector (E). The carbon foils with a thickness of about 150µg/cm^2 were used as a target. Their thicknesses were determined at the proton beam of the UKP-2 accelerator (Almaty, Kazakhstan). The accuracy was not worse than 5%.

Experimental data of elastic scattering were analyzed within the framework of the optical model (OM). For all calculations, the Woods-Saxon form factor was used for both the real and imaginary potential

$$U = V + iW, \quad (1)$$
$$V = V_o\,[1+\exp\,(r-R_r)/a_r]^{-1} \quad (2)$$
$$W = W_o\,[1+\exp\,(r-R_i)/a_i]^{-1} \quad (3)$$

V_o and W_o, a_r and a_i, R_r and R_i being the depth, diffuseness and radii of the real and imaginary potentials, respectively. Parameters of optical potential (OP) were selected to achieve the best agreement between theoretical and the experimental angular distributions (see Table). The description of experimental data is shown in Figure by the dashed blue line. It can be seen that OM well describes the differential cross section of elastic scattering in forward hemisphere.



The angular distributions of elastic and inelasic scattering of ^{13}C on ^{12}C measured at the 32.5 MeV. The red and white circles are experimental data for elastic and inelastic scattering respectively. Curves: the blue dashed line is the optical model prediction; the green solid line represents the coupled reaction channels calculation of elastic scattering by code FRESCO with taking into account the neutron transfer mechanism; the violet dash-dot line represents FRESCO calculation of inelastic scattering for the 2^+ excited state of the ^{12}C nucleus.

Table. Potential parameters.

E (MeV)	V_0 (MeV)	r_V (fm)	a_V (fm)	W_0 (MeV)	r_W (fm)	a_W (fm)	*SF*
32.5	86.602	1.084	0.586	35.563	1.263	0.329	0.93

However, this model does not reproduce the structure of the experimental cross sections at the angles 80-110^o and does not predict the cross section rise at backward direction.

To take into account the neutron transfer mechanism

$$A+(A'+x)\to A'+(A+x) \tag{4}$$

we used the Coupled Reaction Channels method (CRC) realized in the code FRESCO. The calculations were performed with spectroscopic factor SF = 0.93.

So, the neutron transfer mechanism was coupled with the elastic and inelastic scattering. We assume that the rotation is the dominant mechanism for transition to the 2^+ level at the excitation energy of 4.43 MeV of the ^{12}C nucleus. The transition to this level was calculated using the form-factor:

$$V_\lambda(r) = -\frac{\delta_\lambda}{\sqrt{4\pi}}\frac{dU(r)}{dr}, \tag{5}$$

where δ_λ is the length of the multipole (λ) deformation. In our case λ = 2 for the quadrupole transitions. The value of deformation length δ_2 =2.59 fm was extracted from the analysis of experimental data of inelastic scattering. This value corresponds to the deformation parameter β_2 = 1.1 ($\beta_2 = \delta_2/R_V$).

3. Conclusion

The experimental data on elastic and inelastic scattering have been analyzed within the framework of the optical model and the Coupled Reaction Channels method with code FRESCO taking into account the neutron transfer mechanism. OM does not provide cross sections enhancement in backward direction. Only taking into account the neutron transfer mechanism gives rise to cross sections at large angles. So, it is important to extend the measurements for angles greater than 120^o. The value of deformation length δ_2 =2.59 fm was extracted from the analysis of experimental data of inelastic scattering by CRC.

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