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STUDY OF ELASTIC AND INELASTIC SCATTERING OF DEUTREONS BY ^{13}C NUCLEI AT ENERGY E_d=18 MeV

Abstract. The differential cross sections of elastic and inelastic ($3/2^-$ excited state of ^{13}C, E_x = 3.684 MeV) scattering of deuterons by ^{13}C nuclei at energy E_d = 18 MeV in the angular range θ_{lab} = 10°-75° have been measured at the U-150M cyclotron (Almaty, Kazakhstan). The total error of the experimental data obtained does not exceed 10%. The standard dE-E method of registration and identification of interaction products was used in the experiment. Thin carbon films with a thickness of about 150 μg/cm2 of about 80% enrichment by ^{13}C were used as targets. A theoretical analysis was made within the framework of the optical model of the nucleus and the coupled channels method. The values of the quadrupole deformation were determined, which are in good agreement with the literature data. It is shown that in order to improve the theoretical description of experimental data, additional mechanisms (reactions, other inelastic processes) that can influence the formation of scattering cross sections must be taken into account in the calculations.

Key words: differential cross sections, optical potentials, deformation parameters.

Introduction. The success of the diffraction mechanism with strong absorption in explaining the elastic and inelastic scattering of alpha particles has stimulated interest in new research on the scattering of other particles, including deuterons, by light nuclei. Since the structure of the alpha particle is strongly coupled, while the deuteron is weakly coupled, it remains an open question whether diffraction with strong absorption in deuteron scattering plays an equally important role, especially in case of light nuclei.

In recent years, the scattering of deuterons by carbon isotopes nuclei has been investigated at energies from 4 to 17 MeV. Analysis of ^{12}C(d,d)^{12}C the reaction in the energy range 9-14 MeV [1,2] with a simple interaction potential, established the applicability of the optical model for light nuclei. To date, there have been few studies on the scattering of deuterons by ^{13}C nuclei. There are only a few works where elastic scattering was studied at energies of 13.7±17 MeV [3-7]. Data on inelastic scattering are completely absent.

The study of elastic and inelastic processes of interaction of deuterons with nuclei is one of the main sources of information on the properties of the ground and low lying excited states of atomic nuclei [8]. These processes, occurring during collisions of nuclei with energies of several tens of MeV, provide valuable information about the structure of specific nuclear states.

Experimental methods and measurement results.

Measurements of the cross sections for deuteron scattering processes on 13C nuclei were carried out on extracted beams of the U-150M isochronous cyclotron of the Institute of Nuclear Physics (Almaty, Kazakhstan) with an energy of Ed = 18 MeV. The interval of measured angles is 10-75 degrees in the laboratory coordinate system.

The deuteron beam was conducted through a collimation system (two collimators 2 mm in diameter, placed 440 mm from each other) and formed a 2 mm spot on the target. Careful adjustment of the collimator system, as well as the mobile device with a detector for measuring the angular distributions, made it possible to reduce the error in determining the angle to ±0.20°. The experiment used a standard experimental ΔE-E method for detecting and identifying particles.

Thin films of ^{13}C (isotopic enrichment of about 80%) made using electron-beam sputtering were used as targets. During the experiments, several self-sustaining films with a thickness of about 150 μg/cm^2 were used. An example of the spectrum of scattered deuterons on the target is shown in Figure 1.

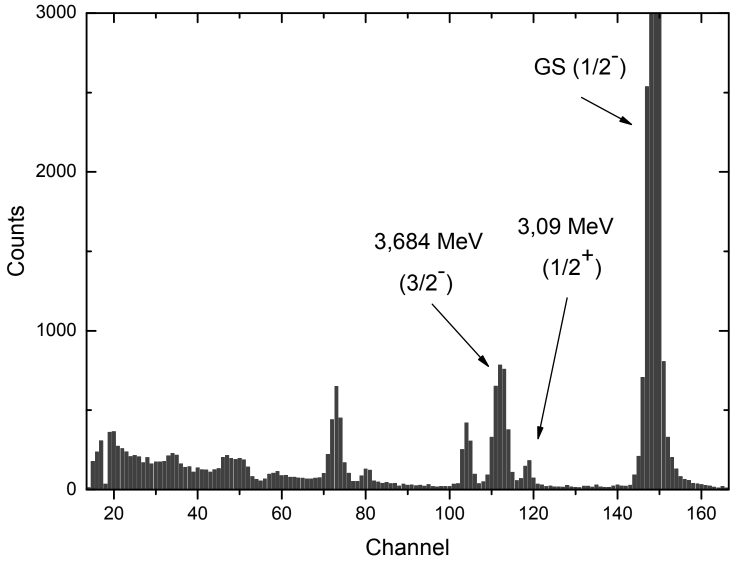

Figure 1 - Spectrum of deuterons scattered by ^{13}C nuclei at an angle of 40 degrees

The total error of the obtained experimental data did not exceed 10 percent. The angular distributions of the measured differential cross sections are presented in Figures 2 and 3 (the symbols are triangles).

Theoretical analysis.

The theoretical elastic scattering cross sections were analyzed using the standard optical model (OM). The calculations were extended using global optical potentials for deuterons obtained in the work of Haixia An [9]. The parameters of the potentials are given in Table 1. Figure 2 presents a comparison of the experimental data with the cross sections calculated within the OM. It can be seen that the calculated cross sections (the solid line in Figure 2) reproduce the experiment quite well.

Table 1 - Optical potential parameters used in the calculations within the framework of optical model and the coupled channels method

V	r_V	a_V	W_S	r_S	a_S	W_D	r_D	a_D	V_{SO}	r_{SO}	a_{SO}	r_C
89,04	1,15	0,75	2,22	1,35	0,62	10,28	1,4	0,68	3,557	0,97	1011	1,303

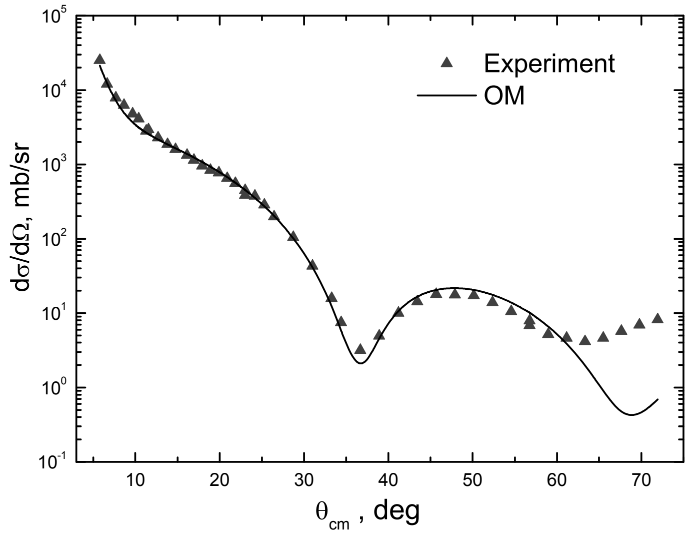

Figure 2. - Comparison of experimental data on elastic scattering with theoretical cross sections calculated within OM using the potentials from Table 1

Inelastic scattering cross sections were calculated within the framework of the coupled channels method (CC) using the FRESCO computer code [10,11]. The coupling between the ground ($1/2^-$) and excited (E_x = 3.684 MeV, $3/2^-$) states of the ^{13}C nucleus in deuteron scattering was taken into account within the framework of the rotational model with the form factor

$$V^{\lambda}(R) = -\frac{\delta_{\alpha}}{\sqrt{4\pi}}\frac{dU(R)}{dR}$$

for quadrupole transitions ($\lambda = 2$), where δ_λ is the length of the multipole deformation.

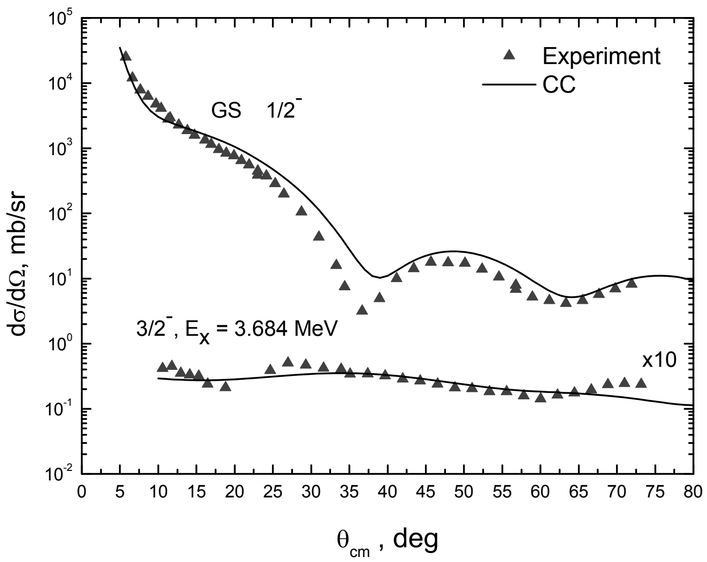

Figure 3 - Comparison of experimental data with theoretical cross sections calculated within the framework of the CC method (elastic scattering is above, inelastic scattering is below)

In the calculations, the potentials from Table 1 were used. The length of the quadrupole deformation was determined from the fit of the calculated cross sections to the experimental data and was $\delta_2 = 0.54$. The found value agrees well with the literature data [12-16]. Figure 3 presents a comparison of the calculated cross sections (solid line) with experimental data. It is seen that the coupling of channels worsened the description of elastic scattering in the region of angles up to 60 degrees. Probably, to eliminate this problem, it is necessary to include additional processes in the coupling: reactions and inelastic channels with excitation of other levels of the ^{13}C nucleus [17-21].

Conclusion. With an error of no more than 10%, the angular distributions of the differential cross sections of elastic and inelastic (excited states of ^{13}C: 3/2$^-$, E_x = 3.684 MeV) scattering of deuterons on ^{13}C nuclei at an energy E_d = 18 MeV in the forward angles region have been measured. The values of the quadrupole defromation are determined, which are in good agreement with the literature data. It is shown that in order to improve the theoretical description of experimental data, additional mechanisms (reactions, other inelastic processes) that can influence the formation of cross sections must be taken into account in the calculations.

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E_d = 18 MeV ЭНЕРГИЯДА ^{13}C ЯДРОЛАРЫНАН ДЕЙТРОНДАРДЫҢ СЕРПІМДІ ЖӘНЕ СЕРПІМСІЗ ШАШЫРАУЫН ЗЕРТТЕУ

Аннотация. $\theta_{lab} = 10^0 - 75^0$ бұрыштар диапазонында E_d = 18 MeV энергиялы дейтрондардың ^{13}C ядроларынан серпімді және серпімсіз (^{13}C ядросының қоздырылған күйі: 3/2$^-$, E_X = 3.684 MeV) шашырау дифференциалдық қимасы У-150М (Алматы, Қазақстан) циклотронында өлшенді. Алынған эксперименттік мәліметтердің толық қателігі 10% аспайды. Экспериментте әсерлесу өнімдерін тіркеу және сәйкестендірі үшін стандартты dE-E әдісі қолданылды. Нысана ретінде қалындығы шамамен 150 мкг/см^2 болатын 80% байытылған ^{13}C жұқа көміртегі қабықшасы пайдаланылды. Теориялық талдаулар ядроның оптикалық моделі және байланысқан арналар әдісі төңірегінде жүргізілді. Анықталған квадрупольді деформация ұзындығының мәні әдебиеттік мәліметтермен жақсы үйлеседі. Эксперименттік мәліметтерді теориялық тұрғыдан дәлелдеуді жақсарту үшін есептеулерде шашырау қималарының пайда болуына әсер ететін қосымша механизмдерді (реакциялар, басқа серпімсіз процесстер) ескеру қажет.

Түйін сөздер: дифференциалдық қима, оптикалық потенциалдар, деформация параметрлері.

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ИССЛЕДОВАНИЕ УПРУГОГО И НЕУПРУГОГО РАССЕЯНИЯ ДЕЙТРОНОВ НА ЯДРАХ ^{13}C ПРИ ЭНЕРГИИ E_d = 18 MeV

Аннотация. На циклотроне У-150М (Алматы, Казахстан) измерены дифференциальные сечения упругого и неупругого (уровень возбуждения ядра ^{13}C: $3/2^-$, E_X = 3.684 MeV) рассеяния дейтронов на ядрах ^{13}C при энергии E_d = 18 MeV в диапазоне углов $\theta_{lab} = 10^0 - 75^0$. В эксперименте использовалась стандартная dE-E методика регистрации и идентификации продуктов взаимодействия. В качестве мишеней использовались тонкие углеродные пленки толщиной порядка 150 мкг/см^2 и обогащением по ^{13}C около 80%. Полная погрешность полученных экспериментальных данных не превышает 10%. Выполнен теоретический анализ в рамках оптической модели ядра и метода связанных каналов. Определены значения длин квадрупольной деформации, которые неплохо согласуются с литературными данными. Показано, что для улучшения теоретического описания экспериментальных данных в расчетах необходимо учитывать дополнительные механизмы (реакции, другие неупругие процессы), которые могут влиять на формирование сечений рассеяния.

Ключевые слова: дифференциальные сечения, оптические потенциалы, параметры деформации.

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