The study of dp -elastic scattering at the energies from 500 to 1000 MeV/nucleon

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The results of the differential cross section measurements of dp -elastic scattering at energies from 500 to 1000 MeV/nucleon at Nuclotron JINR are reported. The data were obtained for angles range of 75° - 120° in the c.m.s. The results are compared with existing world data.

Keywords: dp -elastic scattering; differential cross section.

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1. Introduction

The study of dp -elastic scattering at energies up to 1000 MeV/n at large angles in the c.m.s. is one of the directions of DSS (Deuteron Spin Structure) project research program.¹ Now the different theoretical models are developed to describe of the three-nucleon scattering.²⁻⁵ The experimental material for this reaction covers the energy range from tens to thousands MeV/n.⁶⁻¹⁴ The theoretical calculations using not only 2N forces but also different 3N forces^{15,16} give the best agreement with experimental data. However, the discrepancy between the theory and experiment is increasing with the energy increasing indicating the possibility of relativistic effects. The Glauber scattering theory which takes both single and double interactions a classic approach at the energies higher 400 MeV/n.^{17,18} Relativistic impulse approximation calculations do not describe these data.¹⁹ The experimental data can be fit with a relativistic multiple-scattering theory which uses off-mass-shell extrapolations of the nucleon-nucleon amplitudes suggested by the structure of derivative meson-nucleon couplings.²⁰

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The experimental setup at internal target station (ITS)²¹ at Nuclotron allows to obtain the different observables in the angular range 60–140° in the c.m.s. The new preliminary differential cross section data were obtained at ITS Nuclotron at the energies from 250 to 440 MeV/n.²² Recently, the deuteron vector and tensor analyzing powers have been obtained at 440 MeV/n.²³ The preliminary data of differential cross section for dp-elastic scattering at energies from 500 to 1000 MeV/n, obtained at ITS at Nuclotron are presented in this paper.

2. Experiment and Data Analysis

The measurements were performed at ITS²¹ at the Nuclotron JINR by using 10 μm CH₂ and 8 μm C targets. New ITS DAQ system was used during the data taking.²⁴ The elastically-scattered deuterons and protons were registered by two pairs of scintillation detectors placed symmetrically with respect to the beam direction. Also two scintillation counters (PP-detectors) were used to register the quasi-elastically scattered protons. All counters based on the Hamamatsu H7416MOD PMT previously were used in the experiment.²³ The layout of the counters with respect to the beam direction is shown in Fig. 1.

The D_{1,2}, P_{1,2} and PP_{1,2} are deuteron-, proton- and PP-detectors, respectively. All the counters were placed in horizontal plane. The DP-detectors were rotated to give an angular range of the $\theta_{lab} = 19^\circ$ to 50° ($\theta_{c.m.} = 70^\circ$ to 120°). The PP-detectors were mounted at the angle corresponding to quasi-elastic scattering at $\theta_{c.m.} = 90^\circ$ and remained stationary throughout the experiment. The size of the D-, P- and PP-counters are $10 \times 40 \times 24 \text{ mm}^3$, $20 \times 60 \times 20 \text{ mm}^3$ and $50 \times 50 \times 20 \text{ mm}^3$, respectively. The distances from proton-, deuteron- and PP-counters to the point of the beam interaction with the target are 58, 56 and 56 cm, respectively.

In the case of the measurements at 1000 MeV/n the size of the D-, P- and PP-counters are $50 \times 50 \times 20 \text{ mm}^3$, $20 \times 60 \times 20 \text{ mm}^3$ and $\phi 100 \times 200 \text{ mm}^3$, respectively. The distance between PP_{1,2}- counters and point the beam interaction with the target is 100 cm. Each of such a counter consists of the ΔE and E -detectors.²⁵

Fig. 1. Layout of the counters with respect to the beam direction. D_{1,2}, P_{1,2}- deuteron and proton detectors, PP_{1,2}- detectors to register of the pp-quasi-elastic scattering.

Fig. 2. The procedure of $CH_2 - C$ - subtraction for $\theta_{c.m.} = 70^\circ$ in the c.m.s. at 1000 MeV/n. A — is the CH_2 - and normalized C -distributions given by the solid and dotted histograms, respectively, vertical solid lines — is the interval of the normalization. B — is the result of $CH_2 - C$ subtraction, vertical dashed lines are the window indicating the domain of the dp -elastic scattering events.

The VME based data acquisition system was used for the data taking from scintillation detectors.²⁶ TQDC16 module allows to measure the amplitude and time appearance of the signal.

The data analysis was performed in the following way. The selection of the dp -elastic scattering events was performed by using the graphical cut for amplitude correlation spectra and the temporary gates on the deuteron and proton time difference spectra.²⁷ The next stage is the $CH_2 - C$ subtraction procedure (Fig. 2), the description of which can be found in Ref. 28. The subtraction resulting spectra allows to obtain the dp -elastic scattering events.

The determination of the detectors misalignment was performed at energy 700 MeV/n.

The measurements were performed for each scattering angle in the c.m.s. Since the angle span of the deuteron counter in the c.m.s. is wider than the angle span of the proton counter the deuteron counter is fixed at kinematical angle in the lab. sys. but the proton counter is moved around corresponding angle. The simulation of dp -elastic scattering events by using the Pluto package²⁹ was performed. The statistics in this case is reduced about two times if the shift of the detector equals 2° in the c.m.s. Also the measurements to obtained of the dp -elastic scattering yields were performed (Fig. 3). The founded misalignment equal $1-2^\circ$ in lab.sys.

3. The Differential Cross Section

In Fig. 4 the data for differential cross section at 1000 MeV/n are compared with world data and with the theoretical predictions.³⁰ New data are shown by the solid

Fig. 3. The experimental relative yields for proton detectors as a function of detector angle for $\theta_{c.m.} = 75^\circ$ in the c.m.s. at 700 MeV/n. Filled and open symbols correspond to yields for one and other proton detectors.

Fig. 4. The differential cross section for dp -elastic scattering at 1000 MeV/n. Squares - the results of this work, solid band - the systematic errors, circles - data from Ref. 11, triangles - data from Ref. 13. The dashed and solid lines are the calculations without and with DS term, respectively.

squares. The errors are the statistical only. The systematic error due to normalization and $CH_2 - C$ subtraction procedure $\approx 30\%$. The data obtained earlier for forward angles¹¹ are shown by the solid circles. The open triangles are world data from Ref. 13. The data at Nuclotron are normalized to data from Ref. 13 at 70° in the c.m.s. One can see that the new data at $\theta_{c.m.} \leq 90^\circ$ are in good agreement with the world data. The discrepancy is increasing at large angles, nevertheless, the data are in agreement within the errors which increase with the angle increasing.

Figure 4 shows that the single scattering mechanism does not reproduce the experimental data at the scattering angles $\theta_{c.m.}$ larger than 45° . The inclusion of the double scattering (DS) term in the calculations provides better agreement with the experimental results. However, some discrepancy remains. Probably, taking into account new reaction mechanisms like explicit Δ -isobar excitation will improve the description of the data.

The preliminary data for differential cross section at 700, 650 and 750 MeV/n are shown in Figs. 5–7, respectively. One can see a reasonable agreement of the angular behavior of our data with the existing data.^{10, 12}

Fig. 5. The angular dependence for differential cross section at 700 MeV/n. The data were obtained by using the results of measurements to determinate of the detectors misalignment for each angle scattering.

Fig. 6. The differential cross section for dp -elastic scattering at 650 MeV/n. Squares - the results of this work, solid band - the systematic errors, triangles - data from Ref. 10.

Fig. 7. The differential cross section for dp -elastic scattering at 750 MeV/n. Squares - the results of this work, solid band - the systematic errors, open triangles - data from Ref. 10, solid triangles - data from Ref. 12.

4. Conclusion

The procedure on the dp-elastic scattering differential cross section at high energies at ITS at Nuclotron using $CH2 - C$ subtraction is established.

The data obtained at 1000 MeV/n are compared with the calculations performed within the framework of the relativistic multiple scattering theory. It is shown that taking into account the double scattering term improves the description of the obtained experimental results.

The preliminary differential cross section data for dp-elastic scattering at 650, 700 and 750 MeV/n are obtained. New results are compared with the existing data for similar values of energies.

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