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CALIBRATION MEASUREMENTS OF THE $^{12}C(d, p)$ AND $p(d, p)$ CROSS SECTIONS AT SMALL PROTON MOMENTA IN THE DEUTERON REST FRAME

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The measurements of deuteron stripping cross sections on carbon and CH_2 targets have been carried out in the proton momentum region close to $p_d/2$ (p_d = 9.1 GeV/c). The cross sections of the $p(d, p)$ reaction were extracted using the CH_2-C subtraction method. Extrapolating the data to a zero proton momentum in the deuteron rest frame, we have obtained the cross sections equal to 294.8±3.8 and 54.3±2.9 $b \cdot c^3/GeV^2 \cdot sr$ for the carbon and proton targets, respectively.

The investigation has been performed at the Laboratory of High Energies, JINR.

Калибровочное измерение сечений реакций $^{12}C(d, p)$ и $p(d, p)$ при малых импульсах протона в системе покоя дейтрона

В.Г.Аблеев и др.

При импульсе дейтронов p_d = 9,1 ГэВ/с проведены измерения сечений реакции стриппинга дейтрона на углеродной и CH_2 мишенях в области импульсов протонов, близкой к $p_d/2$. Сечения реакции $p(d, p)$ получены с помощью процедуры вычитания CH_2-C. Экстраполяцией данных к нулевому импульсу протона в системе покоя дейтрона получены сечения 294,8±3,8 и 54,3±2,9 $б \cdot c^3/ГэВ^2 \cdot ср$ для углеродной и протонной мишени соответственно.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Experimental Procedure

The method used to measure the spectra of proton-spectators[1] in a wide momentum region (recent data are published in ref.[2]) does not allow one to find the absolute values of cross sections. To connect spectra measured by the method[1,2] to absolute values a special experiment was performed. The results obtained for the carbon target

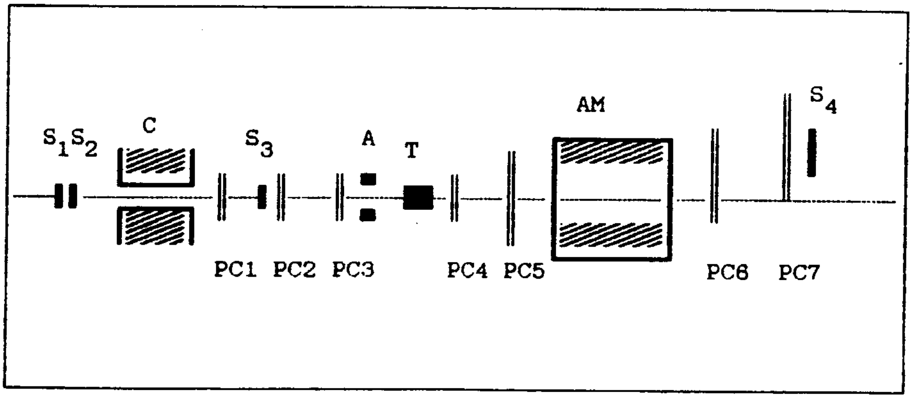

Fig. 1. Schematic layout of the experimental setup (drawing not to scale): S,A – scintillation counters; PC – multiwire proportional chambers; T – target; AM – analysing magnet; C – collimator

were published earlier/3/. To find the absolute values of stripping cross section on hydrogen, it was necessary to improve an off-line procedure used earlier. As a consequence, the old carbon data/3/ were slightly (within the error bars) changed as well.

The experiment was carried out at the JINR synchrophasotron. The spectrometer «ALPHA» in a deuteron beam with momentum 9.1 GeV/c was used (fig.1). To measure the absolute cross sections, it is necessary to detect each incident particle and hence the beam intensity must be lower than about $5\cdot 10^5$ particles per pulse. Therefore it is impossible to use this method for measuring the proton spectrum far from the most probable proton momentum $p_d/2$ because of a fast decrease of the cross sections.

To verify the correctness of taking into account multiple scattering effects and others, two sets of targets (3.01 and 5.96 g/cm^2 (carbon) and 2.61 and 7.19 g/cm^2 (CH$_2$)) were used.

For each incident particle selected by coincidence $M = S1\wedge S2\wedge S3\wedge \bar{A}$ only one track in each chamber upstream the target was required. Stripping events were selected by setting the magnetic field in the analyzing magnet MA (see fig.1) to direct particles with mean momentum $\cong 4.55$ GeV/c to the counter $S4$ (25x30 cm^2). After trigger $T = M\wedge S4$ information from the spectrometer was transferred to an on-line EC1010 computer. Information needed to calibrate the spectrometer, to determine its resolution parameters and to control its performance was taken with trigger $T = M$ which was switched on every tenth pulse.

The angular and momentum resolutions of the spectrometer were respectively $\sigma_\theta \cong 0.9$ mrad and $\sigma_p/p \cong 0.7\%$ for protons with a momentum of about 4.5 GeV/c.

Data Analysis

Because of interaction with background matter on the flight path before the spectrometer and in the counters $S1 \div S3$, the beam hitting the target had an admixture of protons (about 3%) with momentum close to $p_d/2$. This contaminated background proton beam has a larger angular divergence than the primary deuteron beam. The restriction of the input angle of entering particles by 1.5 mrad and of the scattering angle in the counter $S3$ allowed one to suppress appreciably empty-target background.

Only events with one track in each chamber downstream the target were analyzed in the previous track reconstruction procedure. Therefore stripping events accompanied by particle production (primarily pion production) were excluded while no such rejection took place in the main (high luminosity) geometry/1,2/ of the experiment. Pion production accompaniment can be noticeable in some part of the proton spectrum/5/, but it is unessential in the region of proton momenta close to $p_d/2$. This time we used the multitrack reconstruction procedure which confirmed correctness of our previous approach. Nevertheless, this procedure was useful for the following reason. The secondary proton beam has a more wide spatial distribution in the spectrometer area than the one selected by the counters $S1 \div S3$ and the proportional chambers upstream the target. An appreciable number of events with two particles took place within the time gate. Whereas the chambers upstream the target registered only one track in this case, the chambers downstream the target often registered two tracks because of their larger sizes. Multitrack reconstruction with the selection of true events using track matching criteria in the target and in the center of the analyzing magnet allowed us to increase the spectrometer efficiency from 75% to 92%. This improvement is not very essential for increasing statistics, but the higher efficiency the higher accuracy of its evaluation and accordingly the less systematic errors.

To obtain the cross sections, we analyzed the proton momentum distributions of events taken in the deuteron rest frame (DRF), namely:

$$q^2 = q_t^2 + q_l^2, \quad q_t = p \cdot \sin\theta, \quad q_l = F(p \cdot \cos\theta),$$

where p, θ are the momentum and emission angle of the proton in the laboratory, and F the corresponding Lorentz transformation. The q-resolution, σ_q, calculated from quoted above σ_p/p and σ_θ, was $\cong 5$ MeV/c.

Taking into account the isotropy of the proton-spectator angular distribution in the DRF at $q \leq 50$ MeV/c[3,4], we included in our analysis events with any emission angles in the DRF. As a result, the statistics of events was high enough to realize the subtraction (CH_2−C) procedure. To check angular isotropy, we used the Q-distributions of events with Q defined as follows: $Q = q$ if $p > p_d/2$ and $Q = -q$ if $p < p_d/2$ (the sign of Q coincides with the one of q_l).

We excluded events with $\theta \leq 2$ mrad from the analysis because of large empty-target background (which consisted mainly of the proton contamination of the primary beam). «Full-empty» subtraction was performed modifying the «empty target» emission angle distribution, because the admixed protons undergo multiple scattering and energy losses in the «full target» case while in the «empty target» one these effects are almost completely absent. «Full-empty» subtraction was made for each «full target» using correspondingly prepared «empty target» distribution with taken into account multiple scattering parameter of this «full target». This well-defined procedure has been used by us in our studies of forward elastic πp scattering and diffractive αA scattering[6].

Results

The cross sections obtained with a pair of thick and thin targets are in good agreement within the statistical errors. Therefore we integrated these data (see fig.2). Extrapolation to $q = 0$ was made by approximating the data using the simplest of the deuteron wave functions, namely that by Hulten[7], because all known wave functions are undistinguishable at $q < 50$ MeV/c:

$$\varepsilon \cdot d^3\sigma/dq^3 = A \cdot (1 + q^2/\alpha^2)^{-2} \cdot (1 + q^2/\beta^2)^{-2}, \quad \varepsilon = \sqrt{m_p^2 + q^2}, \tag{1}$$

where $\alpha = 45.6$ MeV/c and $\beta = 270$ MeV/c.

The invariant cross sections extrapolated to $q = 0$ are (54.4±2.9) and (294.8±3.8) $b \cdot c^3/GeV^2 \cdot sr$ for hydrogen and carbon with $\chi^2 = 0.48$ and 1.6 per point, respectively. The fit of the $Q > 0$ and $Q < 0$ data for the carbon target (the variable Q is defined above) gave coincident

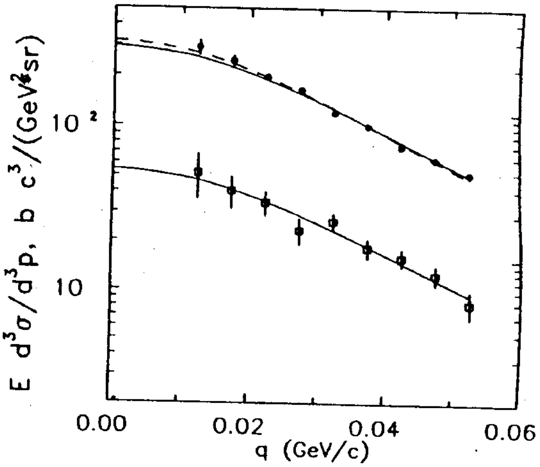

Fig.2. The invariant cross sections of the ^{12}C(*d*, *p*) (○) and *p*(*d*, *p*) (□) reactions. Solid lines – the data fit by formulae (1) with fixed parameter α: dashed line – the data fit with free parameter α

(within the error bars) results; this confirms the angular isotropy assumption for protons emitted at $q < 50$ MeV/c.

We have shown/2/ that the ratio of the cross sections of deuteron fragmentation on carbon and hydrogen depends on q at $q \leq 0.2$ GeV/c: the q-behaviour of the *p*(*d*, *p*) forward cross section follows the standard deuteron wave functions while the C(*d*, *p*) forward cross section decreases faster as q increases. Therefore we made an attempt to fit the carbon data taking the parameter α as a free one. This resulted in the cross section (318.2±13.3) $\text{b}\cdot c^3/\text{GeV}^2\cdot\text{sr}$ at $q = 0$ with $\alpha = 43.5$ MeV/c and $\chi^2 =$ $= 1.3$ per point. The difference in χ^2 is too small to select between these fits, and so the difference in the extrapolated C(*d*, *p*) cross sections at $q = 0$ can be treated as an estimate of systematic uncertainty of the result contributed by the extrapolation procedure.

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