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TENSOR ANALYSING POWER T_{20} IN INELASTIC $(d, d')\,X$ SCATTERING AT 0° ON ^{1}H AND ^{12}C FROM 4.5 TO 9.0 GeV/c

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Tensor analysing power T_{20} for inelastic $(d, d')\,X$ reaction at deuteron momenta from 4.2 to 9 GeV/c is presented. It is observed that T_{20} taken as a function of the four-momentum transfer squared t demonstrates an approximate scaling; its absolute value is small at $|t| <\simeq (0.05 - 0.1)$ GeV^2/c^2 and has a maximum at $-t \simeq 0.3$ GeV^2/c^2. No significant dependence on the type of the target was observed.

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

Тензорная анализирующая способность T_{20} в неупругом $(d, d')\,X$-рассеянии под 0° на ^{1}H и ^{12}C от 4,5 до 9,0 ГэВ/с

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Представлены данные о тензорной анализирующей способности T_{20} неупругой реакции $(d, d')\,X$ при импульсе дейтронов от 4,2 до 9 ГэВ/с. Обнаружен приближенный скейлинг для T_{20}, когда она представлена в зависимости от квадрата переданного 4-импульса t; абсолютная величина T_{20} невелика при $|t| <\simeq (0{,}05 - 0{,}1)$ ГэВ^2/с^2 и имеет максимум при $-t \simeq 0{,}3$ ГэВ^2/с^2. Сколько-нибудь заметной зависимости от типа мишени не замечено.

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1. Introduction

Excitation mechanisms and properties of broad hadronic resonances in nuclei intimately related with nuclear medium response on high energy excitations, have attracted much attention during the last decade (see Ref. 1).

The main interest in these topics and main difficulties as well, come from the simple circumstance that the behaviour of nuclear matter at high excitation energies is governed not only by the nucleonic degrees of freedom but also by internal degrees of freedom of the constituent nucleons: they cannot be treated independently when the energy transferred to the medium is close to the characteristic energy of excitation of the internal degrees of freedom. Such excitations can reveal themselves as $N \rightarrow N^*$, Δ (etc.) transitions followed by radiation of particles from the nuclei.

The well-known example of the non-trivial difference between excitation of resonances off protons and nuclei was found in experiments on inelastic charge-exchange, where it was established that the properties of Δ-isobar excitations of nuclei cannot be accomodated in the picture of quasifree production and indicate a collective response of nuclear matter to high (~ 300 MeV) spin-isospin excitations [2].

New valuable information is to come from studies of polarization effects in processes with excitations of broad hadronic resonances in nuclear medium. A difference between proton and nuclear targets could be expected [3] for some polarization observables, but there were only a few experiments exploring the polarization observables of these reactions [4].

The data on tensor analysing power, T_{20}, of inelastic $p(d, d')X$ and $C(d, d')X$ scattering at 0°, presented here, cover a region of the missing mass M_X from 1 GeV to 2.4 GeV (which contains Δ, $N(1440)$ and heavier baryon resonances) with 4-momentum transfer squared, $-t \leq 0.64$ GeV^2/c^2; the domain ($M_X \leq 1.7$ GeV, $-t \leq 0.3$ GeV^2/c^2) was mapped in more detail.

An independent reason for our interest in the inclusive inelastic (d, d') reaction when deuterons are scattered at 0° is polarimetry of relativistic deuterons at high energies. The data tables presented here demonstrate that this reaction can be used as an analysing reaction when measurements of tensor polarization of relativistic deuterons are necessary.

The experiments and the data analysis procedure are briefly outlined in Sec.2; more detailed description is given in Refs. 5,6,7. Data tables are given in Sec.3.

2. Experiment and Data Analysis

The experiments were performed at the Laboratory of High Energies of the Joint Institute for Nuclear Research (JINR) using tensorially polarized deuteron beam of the Synchrophasotron at initial momenta of 4.495, 5.532, and 9 GeV/c. Description of the measurements at 4.495 and 5.532 GeV/c is given in Ref. 5. Data at 9 GeV/c were taken during concurrent inclusive experiment on deuteron break-up on hydrogen described in Ref. 6; several data points were obtained as a byproduct of the experiment on backward elastic

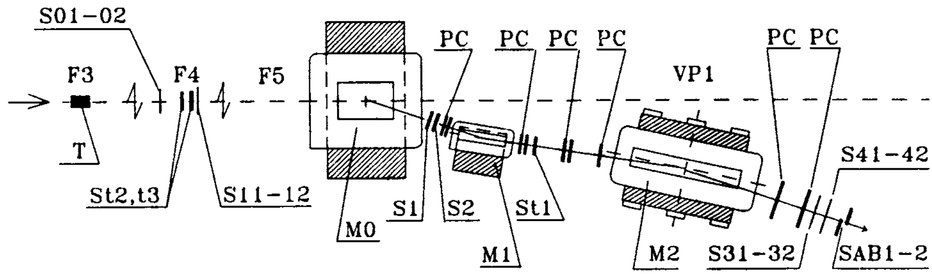

Fig.1. ALPHA-spectrometer at the VP1 beam line. PC: multi-wire proportional chambers; S01–02, St1–St3, S11–12, S31–32, S41–42: scintillation counters of the TOF-system; S1, S2, SAB1–2: trigger scintillation counters; M2: the analysing magnet. The TOF-base between S11–12 and S41–42 was about 50 m

dp scattering [7] at momenta from 4.2 to 6.5 GeV/c also. ALPHA-set-up (shown in Fig.1) was used in all the measurements.

In all these experiments the sign of the beam polarization was changed in a cyclic fashion, «burst-after-burst», as (0, –, +), where «0» means absence of polarization, « – » and «+» correspond to the sign of the $P_{zz} = \sqrt{2}\rho_{20}$; the quantization axis was perpendicular to the plane containing the mean beam orbit in the accelerator. The polarization of the beam was measured with the ALPHA-polarimeter [8] before and after data taking; averaged values of the polarization were slightly different in different experiments (see Refs. 5,6,7) with typical values close to $|P_{zz}^{(+/-)}| = 0.8$. Other beam parameters (positions and widths of the beam spot at control points) together with parameters of the machine, were monitored by the beam control system of the accelerator. This information was recorded for each burst and was used in the off-line analysis where the stability of the beam parameters at the target point was checked.

The 30 cm liquid hydrogen (LH2) or 5.7 cm carbon (C) targets (T) were placed at the focus F3 of the slowly extracted beam. Two beam-intensity monitors were placed upstream from the target: an ionization chamber (used in all measurements) and a scintillation counter operated in the counting mode but at lowered high voltage in order to avoid overloading at intensities of 10^7 deuterons per burst or higher (used in the experiments at lower energies).

The deuterons scattered at 0° and the unscattered part of the primary beam entered the beam line VP1; dipole magnets placed between the foci F3 and F4 (not shown in Fig.1) removed the unscattered part of the beam while the secondaries were transported further to the ALPHA-spectrometer (Fig.1). The momentum acceptance of the set-up was mostly determined by the sizes of the trigger scintillation counters S1, S2, St1 and SAB1, 2; it was $\Delta p/p \simeq \pm 5\%$ typically. The measurements were performed in several steps by changing the spectrometer and the VP1 beam line tuning for a continuous coverage of the momentum spectrum. At every setting,the intensity of the primary beam was optimized for a reasonable counting rates in the counters at the F4 point. At lower energies data were taken with both the LH2 and C targets at each setting; at 9 GeV/c the data were obtained mostly from measurements with the LH2 target. For each primary energy data were also taken without target at most settings. At momenta 4.5 and 5.5 GeV/c the «no-target» background was not more than 10 % at $Q > 0.6$ GeV, mostly coming from scattering on material of the monitor detectors and air around the target position, and less than 50 % at $Q \simeq 0.4$ GeV; the latter comes mostly from scattering of the primary beam on material of the VP1 elements (not shown in Fig.1) between F3 and F5 foci. The transferred energy, Q, is defined as $Q = E_d - E_{d'}$, where E_d is the energy of the projectile and $E_{d'}$ is the energy of the scattered deuteron.

The momentum of the detected particles was measured with accuracy $\sigma_p/p \simeq 0.25$ %. The final resolution of the TOF system after all usual corrections was $\sigma_{\mathrm{TOF}} \simeq 0.24$ nsec. Particle identification was performed using momentum and TOF information; the resolution of the apparatus provided a complete separation between protons, pions and deuterons. Only completely reconstructed events within the spectrometer momentum acceptance were taken for T_{20} calculation. The resolution on Q was typically $\sigma_Q \simeq 15$ MeV.

The spectrometer acceptance is symmetrical over azimuthal angle for deuterons detected at 0°. When the spin quantization axis is perpendicular to the particles momenta, the cross section expressed in terms of spherical tensor analysing powers [9] contains only the T_{20} term, as the contribution with T_{22} is zero for reasons of symmetry. Therefore T_{20} can be calculated directly from the numbers $n_\pm$ of «good» events detected for the «+» and «–» modes of the beam polarization, normalized to the corresponding monitor numbers (the last part of Eq.(1) is valid when $|\rho_{20}^{(+)}| \simeq |\rho_{20}^{(-)}|$):

$$T_{20} = \frac{2(n_- - n_+)}{\rho_{20}^{(+)} n_- - \rho_{20}^{(-)} n_+} \simeq \frac{4}{|\rho_{20}^{(+)}| + |\rho_{20}^{(-)}|} \cdot \frac{n_- - n_+}{n_+ + n_-} . \qquad (1)$$

We estimate the overall systematical uncertainty in T_{20} as $\sigma_{T_{20}\mathrm{syst}} \simeq 0.05$ which is about the same size as the typical statistical uncertainty (see Refs. 5,6,7).

Details of the data analysis procedure are described in Refs. 5,6,7. It includes determination of calibration constants, track reconstruction, determination of time of flight, particle identification, sorting of events according labels of the beam polarization modes, etc.

3. Data Tables

The final data on T_{20} are presented below in Tables. Data for 4.495 and 5.532 GeV/c were published in graphical form in Ref. 5. Data tables from Ref. 7 are included in the present paper for completeness.

In Tables 1—4 the data are presented in dependence upon the transferred energy Q because of the well-known feature of experiments with fixed emission angle: changing Q one changes both t — the 4-momentum transfer squared — and the missing mass, as shown in Fig.2.

Table 1. T_{20} **for** $p(d, d')X$ **at 4.495 and 5.532 GeV/c; only statistical errors are presented**

Initial momentum 4.495 GeV/c			Initial momentum 5.532 GeV/c		
Q, GeV	t', GeV^2/c^2	T_{20}	Q, GeV	t', GeV^2/c^2	T_{20}
3.6875E-01	-2.7834E-02	-0.090 ± 0.043	2.2500E-01	-9.1112E-03	0.102 ± 0.092
4.3125E-01	-3.7936E-02	-0.142 ± 0.048	2.7000E-01	-1.1814E-02	-0.177 ± 0.016
4.6250E-01	-4.3692E-02	-0.028 ± 0.045	3.1786E-01	-1.5289E-02	-0.141 ± 0.098
4.9375E-01	-4.9935E-02	-0.100 ± 0.054	3.5000E-01	-1.7978E-02	-0.079 ± 0.094
5.2500E-01	-5.6677E-02	-0.120 ± 0.044	4.1071E-01	-2.3861E-02	-0.065 ± 0.107
5.5625E-01	-6.3933E-02	-0.067 ± 0.065	4.3000E-01	-2.5955E-02	-0.106 ± 0.085
5.8750E-01	-7.1715E-02	-0.172 ± 0.045	5.0357E-01	-3.4971E-02	-0.051 ± 0.110
6.1875E-01	-8.0039E-02	-0.187 ± 0.039	5.1000E-01	-3.5839E-02	-0.093 ± 0.082
6.5000E-01	-8.8918E-02	-0.216 ± 0.050	5.9000E-01	-4.7728E-02	-0.180 ± 0.028
6.8125E-01	-9.8369E-02	-0.172 ± 0.034	6.5000E-01	-5.8026E-02	-0.201 ± 0.027
7.1250E-01	-1.0841E-01	-0.288 ± 0.062	6.7000E-01	-6.1731E-02	-0.146 ± 0.093
7.4375E-01	-1.1905E-01	-0.232 ± 0.031	7.1000E-01	-6.9560E-02	-0.207 ± 0.027
7.7500E-01	-1.3032E-01	-0.255 ± 0.071	7.7000E-01	-8.2380E-02	-0.221 ± 0.021
8.0625E-01	-1.4222E-01	-0.271 ± 0.034	8.3000E-01	-9.6542E-02	-0.276 ± 0.020
8.3750E-01	-1.5479E-01	-0.245 ± 0.045	8.9000E-01	-1.1210E-01	-0.318 ± 0.023
8.6875E-01	-1.6803E-01	-0.386 ± 0.043	9.5000E-01	-1.2912E-01	-0.335 ± 0.026
9.0000E-01	-1.8197E-01	-0.345 ± 0.040	1.0100E+00	-1.4765E-01	-0.341 ± 0.027
9.3125E-01	-1.9664E-01	-0.474 ± 0.060	1.0700E+00	-1.6778E-01	-0.397 ± 0.031
9.6250E-01	-2.1205E-01	-0.416 ± 0.040	1.1300E+00	-1.8956E-01	-0.466 ± 0.051
1.0250E+00	-2.4518E-01	-0.472 ± 0.048			
1.0875E+00	-2.8159E-01	-0.546 ± 0.063			

It seems that t — the 4-momentum transfer squared — is the best variable for discussion of the data because an approximate scaling of T_{20} is obvious when data are plotted versus t (Fig.3,4). Calculating t and the missing mass M_{miss}, a small correction was taken into account, which comes from the finite angular acceptance (15 msr) of the set-up: it

Table 2. T_{20} for C(*d*, *d* ′) *X* at 4.495 and 5.532 GeV/c; only statistical errors are presented

Initial momentum 4.495 GeV/c			Initial momentum 5.532 GeV/c		
Q, GeV	t', GeV^2/c^2	T_{20}	Q, GeV	t', GeV^2/c^2	T_{20}
3.6875E − 01	− 2.7834E − 02	− 0.077 ± 0.048	2.2500E − 01	− 9.1112E − 03	− 0.090 ± 0.107
4.3125E − 01	− 3.7936E − 02	− 0.036 ± 0.052	3.1786E − 01	− 1.5289E − 02	− 0.038 ± 0.112
4.6250E − 01	− 4.3692E − 02	− 0.014 ± 0.044	4.1071E − 01	− 2.3861E − 02	− 0.141 ± 0.123
4.9375E − 01	− 4.9935E − 02	− 0.128 ± 0.057	5.0357E − 01	− 3.4971E − 02	0.079 ± 0.142
5.2500E − 01	− 5.6677E − 02	0.035 ± 0.045	5.9000E − 01	− 4.7728E − 02	− 0.228 ± 0.036
5.5625E − 01	− 6.3933E − 02	− 0.084 ± 0.070	6.5000E − 01	− 5.8026E − 02	− 0.224 ± 0.035
5.8750E − 01	− 7.1715E − 02	− 0.051 ± 0.048	7.1000E − 01	− 6.9560E − 02	− 0.172 ± 0.035
6.1875E − 01	− 8.0039E − 02	− 0.260 ± 0.033	7.7000E − 01	− 8.2380E − 02	− 0.253 ± 0.025
6.5000E − 01	− 8.8918E − 02	− 0.213 ± 0.057	8.3000E − 01	− 9.6542E − 02	− 0.266 ± 0.025
6.8125E − 01	− 9.8369E − 02	− 0.230 ± 0.031	8.9000E − 01	− 1.1210E − 01	− 0.333 ± 0.028
7.1250E − 01	− 1.0841E − 01	− 0.261 ± 0.076	9.5000E − 01	− 1.2912E − 01	− 0.360 ± 0.031
7.4375E − 01	− 1.1905E − 01	− 0.203 ± 0.031	1.0100E + 00	− 1.4765E − 01	− 0.357 ± 0.033
7.7500E − 01	− 1.3032E − 01	− 0.213 ± 0.055	1.0700E + 00	− 1.6778E − 01	− 0.352 ± 0.038
8.0625E − 01	− 1.4222E − 01	− 0.278 ± 0.035	1.1300E + 00	− 1.8956E − 01	− 0.355 ± 0.069
8.3750E − 01	− 1.5479E − 01	− 0.270 ± 0.042			
8.6875E − 01	− 1.6803E − 01	− 0.309 ± 0.045			
9.0000E − 01	− 1.8197E − 01	− 0.358 ± 0.039			
9.3125E − 01	− 1.9664E − 01	− 0.498 ± 0.063			
9.6250E − 01	− 2.1205E − 01	− 0.421 ± 0.042			
1.0250E + 00	− 2.4518E − 01	− 0.417 ± 0.051			
1.0875E + 00	− 2.8159E − 01	− 0.508 ± 0.070			

allows small transverse component $q_\perp$ of the transferred momentum. It was assumed, when calculating the averaged transverse momentum transfer, that the inelastic *p*(*d*, *d* ′) scattering has the $q_\perp$ dependence similar to that of the elastic *dp* scattering, i.e., exp $(-bq_\perp^2)$, with the

Table 3. T_{20} for $p(d, d')X$ and $C(d, d')X$ at 9 GeV/c; only statistical errors are presented

$p(d, d')X$		$C(d, d')X$	
t', GeV^2/c^2	T_{20}	t', GeV^2/c^2	T_{20}
– 0.040	– 0.219 ± 0.029	– 0.080	– 0.254 ± 0.166
– 0.080	– 0.311 ± 0.027	– 0.120	– 0.481 ± 0.085
– 0.120	– 0.393 ± 0.033	– 0.160	– 0.440 ± 0.068
– 0.160	– 0.451 ± 0.048	– 0.200	– 0.526 ± 0.065
– 0.200	– 0.576 ± 0.055	– 0.240	– 0.612 ± 0.073
– 0.400	– 0.440 ± 0.101	– 0.280	– 0.488 ± 0.090
– 0.240	– 0.608 ± 0.061	– 0.320	– 0.366 ± 0.138
– 0.320	– 0.563 ± 0.073	– 0.360	– 0.377 ± 0.208
– 0.360	– 0.634 ± 0.086		
– 0.280	– 0.480 ± 0.066		
– 0.440	– 0.172 ± 0.116		
– 0.480	– 0.262 ± 0.126		
– 0.520	– 0.235 ± 0.142		
– 0.560	– 0.106 ± 0.147		
– 0.600	– 0.293 ± 0.164		
– 0.640	– 0.051 ± 0.215		

slope parameter close to that of the elastic scattering in our energy region ($\simeq$ 37 GeV^{-2}/c^{-2} [10]). In other words,

$$t' = Q^2 - (p_0 - p_{d'})^2 - \langle q_\perp^2 \rangle = t - \langle q_\perp^2 \rangle;$$

the correction from $\langle q_\perp^2 \rangle$ is very small for t and can be ignored for the mission mass. Data for 9 GeV/c (Table 3) are presented here only versus t'.

No significant dependence on the target (free protons or nuclei) was observed.

At present, theory does not provide a basis for discussion of these data. But independently of any interpretation, the data demonstrate that this reaction can be used for the polarimetry of tensorially polarized deuterons at high energies.

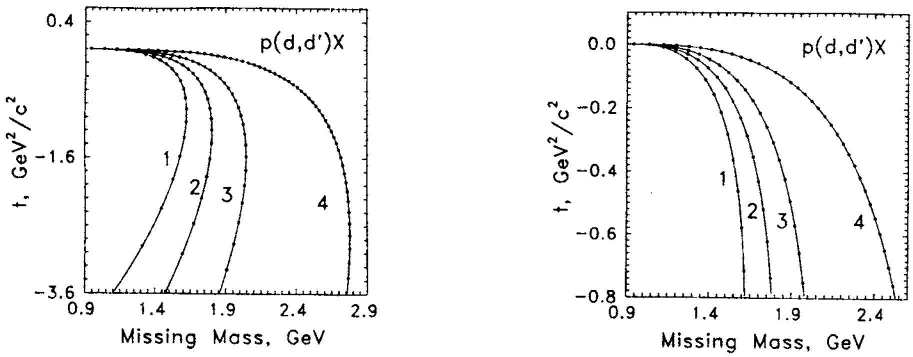

Fig.2. (*d, d'*) kinematics for 0°. 1: 3.73 GeV/c; 2: 4.495 GeV/c; 3: 5.532 GeV/c; 4: 9.0 GeV/c. Dots on the curves are placed with 100 MeV steps on the trasferred energy *Q*. The kinematical curve for 3.73 GeV/c is presented here for completeness; it corresponds to Saclay energy region

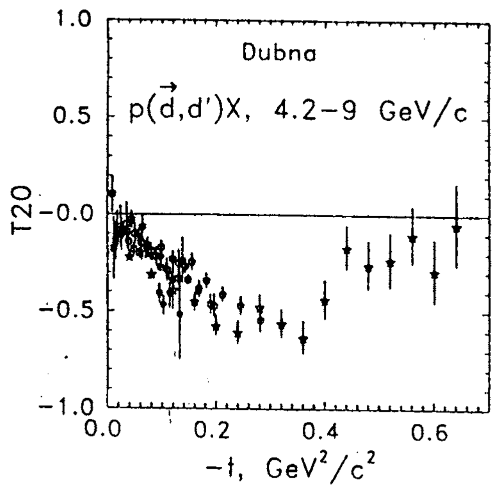

Fig.3. *p*(*d, d'*) *X*, Dubna. Stars: 9 GeV/c, open squares: 5.532 GeV/c, open circles: 4.495 GeV/c, full circles: data from paper [7] for momenta 4.24–6.55 GeV/c

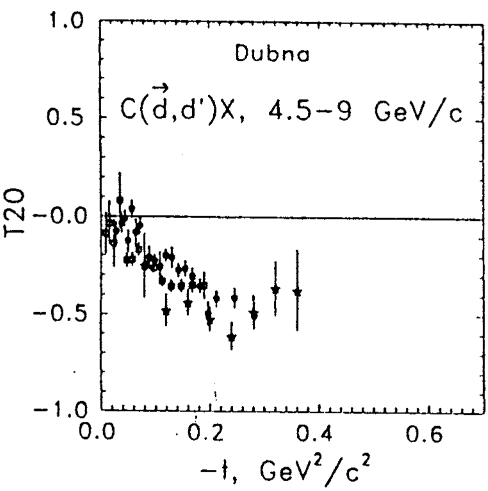

Fig.4. *C*(*d, d'*) *X*, Dubna. Stars: 9 GeV/c, open squares: 5.532 GeV/c, full circles: 4.495 GeV/c

Table 4. T_{20} for $p(d, d')X$ at 4.2—6.5 GeV/c [7]; only statistical errors are presented

Initial p_d, GeV/c	Q, GeV	t', GeV^2/c^2	T_{20}
4.24	7.3577E – 01	– 1.3233E – 01	– 0.52 ± 0.23
4.46	7.8790E – 01	– 1.3753E – 01	– 0.24 ± 0.12
4.69	7.7756E – 01	– 1.1953E – 01	– 0.34 ± 0.15
4.96	8.0323E – 01	– 1.1357E – 01	– 0.41 ± 0.08
5.41	8.0448E – 01	– 9.4669E – 02	– 0.41 ± 0.05
5.96	9.1731E – 01	– 1.0215E – 01	– 0.47 ± 0.05
6.55	8.6007E – 01	– 7.3717E – 02	– 0.16 ± 0.04
6.55	9.8330E – 01	– 9.7299E – 02	– 0.22 ± 0.04

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