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SCALING BEHAVIOUR OF TENSOR ANALYZING POWER (A_{yy}) IN THE INELASTIC SCATTERING OF RELATIVISTIC DEUTERONS

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We suggest a new dimensionless relativistic invariant variable $\Re = \Delta m_X \ / \nu$ which may be interpreted as the ratio of the excitation energy to the full transferred energy; therefore this variable measures a «degree of inelasticity» of the scattering.

Existing data on the tensor analyzing power of the $p(\vec{d},d')X$ and $^{12}C(\vec{d},d')X$ inelastic scattering at momenta from 4. 2 to 9 GeV/c are analysed in terms of this variable.

We observe that A_{yy} taken as a function of $\Re$ does not depend upon the incident energy, the scattering angle (up to the angles of $\vartheta_{cm} \sim 30°$), and there is no noticeable difference between the proton and nuclear targets as well.

It is remarkable that A_{yy} is maximal (of ~0.5) when $\Re \sim 0.5$—0.6 and is small in absolute value when $\Re$ is close to its limiting values of 0 and 1.

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

Скейлинговое поведение тензорной анализирующей способности (A_{yy}) в неупругом рассеянии релятивистских дейтронов

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Введена новая безразмерная релятивистски–инвариантная переменная $\Re = \Delta m_X \ / \nu$, интерпретируемая как часть переданной энергии, затраченная на возбуждение внутренних степеней свободы взаимодействующих частиц. Предложенная переменная может служить «мерой неупругости» процесса.

В терминах переменной $\Re$ рассмотрено поведение анализирующей способности в неупругом рассеянии поляризованных дейтронов $p(\vec{d},d')X$ и $^{12}C(\vec{d},d')X$ при импульсах пучка от 4,2 до 9 ГэВ/с. Установлено, что A_{yy}, как функция $\Re$, одинакова при различных начальных импульсах дейтронов, различных углах рассеяния (до ϑ_{cm}~30°) и при обеих мишенях.

Отметим, что A_{yy} имеет максимум (~0,5) при $\Re \sim 0.5$—0.6 и близка к нулю в районе обеих границ области значений $\Re$ (0 и 1).

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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1. Introduction

The set of experiments measuring the tensor analyzing power (A_{yy}) of inelastic ($\vec{d}, d'$) scattering at the lab. angles of 0° and ~5° off protons and carbon nuclei in the deuteron momentum range from 4 to 9 GeV/c was performed in Dubna in 1994—97 (Refs.1, 2, 3). It was stressed in Refs. 1, 2, 4 that the region of initial deuteron momentum of ~3 to 9 GeV/c is the optimal one for studies of the lowest baryon resonances such as $\Delta(1232)$ and $N^*(1440)$. Data on polarization characteristics of these reactions are of a special interest because of the «spin-isospin filtering» (see Ref.4 and references therein) of different mechanisms, what can be used for better understanding of the mechanisms of the resonance excitations and properties of the relevant resonances.

The A_{yy} data published in Refs.1, 2, 3 were obtained at different energies and angles; therefore t, the 4-momentum transfer squared, was used in order to analyse and compare data obtained at different kinematical conditions. It was noticed that A_{yy} plotted versus t demonstrates an approximate scaling (see Fig.1 and Refs.1, 2). It means that at different momenta of initial deuterons, the behaviour of the $A_{yy}(t)$ is approximately the same. At the lab. scattering angle of 0° the tensor analyzing power $T_{20} = -\sqrt{2} \cdot A_{yy}(t)$ is negative in the explored t-interval ($0 < -t < 0.6$ GeV^2/c^2). It is small in absolute value at small $-t$ and at $-t > 0.4$ GeV^2/c^2, the absolute value reaches its maximum at $0.2 < -t < 0.4$ GeV^2/c^2. Moreover the approximately universal behaviour of $T_{20}(t)$, or the scaling, was observed not only at different momenta of initial deuterons but when the deuteron is scattered on proton or carbon targets.

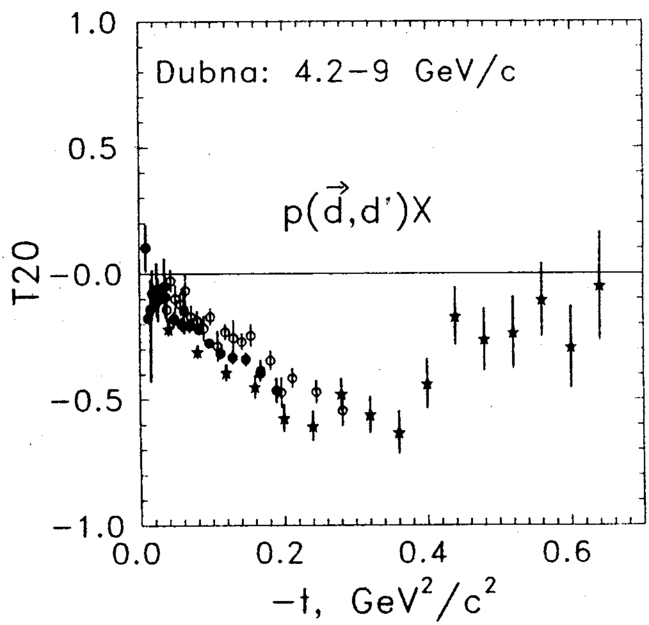

Fig. 1. $T_{20}(t)$ for $p(\vec{d}, d')X$ from Ref. 2. Open circles: 4.2—4.5 GeV/c; full circles: 5.53 GeV/c; stars: 9 GeV/c

Still, it was noticed that the scaling is not perfect: data sets taken at different energies but at the same scattering angle are systematically shifted as a whole relative to each other (see Fig.1). This shift is small and comparable with the error bars, but noticeable. On the other hand, existence of the approximate scaling pointed on a possibility that a better scaling relative to a better variable might be found.

In this paper we suggest such variable. It is relativistic invariant, dimensionless and has rather clear interpretation; these features make this variable rather attractive.

Let us define the relativistic invariant dimensionless quantity

$$\Re = \frac{\Delta m_X}{\nu}, \ \nu = \frac{1}{m_t}\mathcal{P}_t(\mathcal{P}_d - \mathcal{P}_{d'}) = m_d u_t(u_d - u_{d'}), \tag{1}$$

where $\mathcal{P}_d, \mathcal{P}_{d'}$ and $\mathcal{P}_t$ are 4–momenta of the projectile, the ejectile and the target respectively; u_d, $u_{d'}$ and u_t are the 4–velocities of these particles. The $\Delta m_X = m_X - m_t$ is the difference between masses of the recoiled system in the final state (the missing mass, m_X) and the initial state (the target mass, m_t) respectively. In other words, this difference is the energy absorbed by internal degrees of freedom of the colliding particles (obviously, for elastic scattering one has $\Delta m_X = 0$, hence $\Re = 0$ in this special case).

It is interesting that $\Re$ can be rewritten in the form which reminds variables widely used in analysis of lepton deep inelastic scattering:

$$m_X^2 = m_t^2 + t + 2m_t\nu; \ \Re + \frac{\Delta m_X^2 - t}{2m_t\nu} = 1 \ \text{ or } \ \Re\left(1 + \frac{\Delta m_X}{2m_t}\right) = 1 + \frac{t}{2m_t\nu}.$$

It is easy to see that *in the target rest frame*

$$\Re = \frac{\Delta m_X}{Q} = 1 - \frac{T_X}{Q}$$

(where Q is the energy transfer from the projectile to the target, and T_X is kinetic energy of the recoiled system).

Therefore it is possible to interpret $\Re$ as the part of transferred energy which was absorbed by constituents of the target system. In other words, this variable can be considered as a measure of the *inelasticity* of the scattering: it differs from zero **only for an inelastic scattering.**

2. Behaviour of the Analyzing Power as a Function of the Inelasticity Variable $\Re$

First, it is necessary to emphasize that no assumptions about reaction mechanisms, structure of fragments and so on are made in this paper.

The tensor analyzing power $T_{j\mu}$ can be defined for reactions where the incident particle has spin larger than 1/2 as follows:

$$T_{j\mu} = \mathrm{Tr}\{MS_{j\mu}M^+\} \,/\, \mathrm{Tr}\{MM^+\},$$

where the M is the scattering amplitude. For the case of spin 1 it can be written in terms of the reaction cross sections σ_+, σ_- and σ_0 for states with the spin projections onto the quantization axis $S_z = +1, 0, -1$, respectively, as follows:

$$T_{20} = \frac{1}{\sqrt{2}} \cdot \frac{\sigma_+ + \sigma_- - 2\cdot\sigma_0}{\Sigma}; \quad \Sigma = \sigma_+ + \sigma_- + \sigma_0.$$

The cross section can be expressed in terms of the spherical tensor operators according to Madison Convention [5].

The data on T_{20} published in Refs.1, 2 for the inelastic $p(\vec{d},d')X$ scattering of relativistic deuterons at $\vartheta_{lab} = 0°$ are plotted on Fig.2 versus $\mathfrak{R}$.

In contrast with the same data plotted versus t on Fig.1, there is no visible tendency of a systematic shift between data taken at different incident energies on Fig. 2. All the data show a universal dependence on $\mathfrak{R}$; the absolute value of T_{20} has a maximum at $\mathfrak{R} \sim 0.5$–0.6.

Apart from the data taken at $\vartheta_{lab} = 0°$ from Refs.1, 2, recently a new set of the data on the analyzing power for inelastic scattering of deuterons off carbon nuclei at 9 GeV/c were published in Ref.3. These data were taken at $\vartheta_{lab} \sim 85$ mrad (i.e., $\vartheta_{lab} \sim 27°$–$35°$).

Because at the scattering angles larger than $\vartheta_{lab} = 0°$ not only T_{20} enters in the cross sections for polarized particles of spin 1, it is more convenient to use the so-called «carthesian» representation of the analyzing powers. In the experiment of Ref.3 the analyzing power A_{yy} was actually measured. Fortunately, at $\vartheta_{lab} = 0°$ the A_{yy} is related with T_{20} in a rather simple way:

$$A_{yy} = -\frac{1}{\sqrt{2}} T_{20}$$

what makes it passible to plot all the available data versus $\mathfrak{R}$ on Fig. 3. Calculating $\mathfrak{R}$, we assume quasi–free $d + p$ kinematics, i.e., m_t in Eq. (1) is the nucleon mass as was in the case of $p(d,d')X$ scattering.

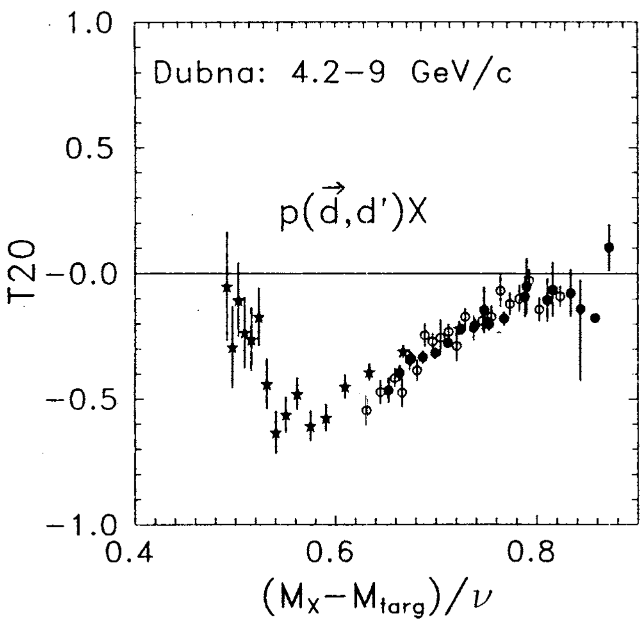

Fig.2. Data from Fig.1 plotted versus $\mathfrak{R}$

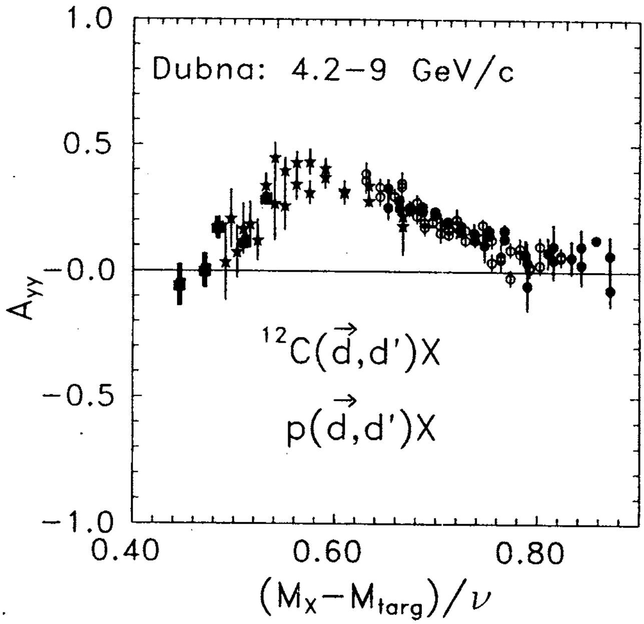

Fig.3. $A_{yy}(\Re)$ for $p(\vec{d},d')X$ and $^{12}C(\vec{d},d')X$ inelastic scattering; data are taken from Refs.2, 3. Open circles: 4.2–4.5 GeV/c; full circles: 5.53 GeV/c; stars: 9 GeV/c; full squares: 9 GeV/c at 85 mrad scattering angle, carbon target [3]

As one can see from Fig. 3, the data taken at 85 mrad support the general tendency in the behaviour of tensor analyzing power, which was observed at zero angle.

3. Conclusions

We have suggested a new relativistic invariant and dimensionless variable for inelastic processes, which takes a constant value equal to zero for any elastic scattering process. This variable may be interpreted as a ratio of the excitation energy to the full transferred energy taken in the target rest frame. Therefore it is a measure of the degree of «inelasticity» of the scattering process; in this aspect it reminds the similar parameter introduced in Ref.6.

We see that A_{yy} taken as function of $\Re$ does not depend upon the initial momentum, the scattering angle and the sort of the target. We see also that when the transferred energy is shared in almost equal proportions between the internal degrees of freedom of the colliding particles and the kinetic motion of the recoiled system as a whole, the A_{yy} is maximal.

This observation inspires an assumption that this might be a general feature of the inelastic reactions with polarized particles: when the ratio between the «absorbed» and transferred energies is close to 0.5–0.6, the polarization effects are strong, while when this ratio is close to its limits (0 and 1), the polarization effects are weak.

Acknowledgments

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4. Appendix

In the case of elastic scattering, the ratio $\Re$ is zero identically. Therefore this is «genuine inelastic» variable. On the other hand, it is easy to see that when one starts from the inelastic scattering at $\vartheta_{\text{lab}} = 0$ and approaches to the elastic limit $m_X \to m_t$ keeping the scattering angle fixed, one gets $\Re \to 1$ but crosses the unphysical region where $m_X - m_t < m_{\min}$, i.e., where inelastic processes are kinematically forbidden because the $m_{\min}$ is the mass of the lightest particle which can be created in the reaction under consideration. At the same time, $\Re \to 0$ if $m_X = m_t$ (fixed) and $\vartheta_{\text{lab}} \to 0$.

That means that there exists a «singular point», because the value of the limit depends upon the way of approaching that point.

On the other hand, in the completely inelastic limit (the missing mass is at its maximal value allowed by the conservation laws at given energy, i.e., $m_X = \sqrt{S} - m_{d'}$), the lab. scattering angle is zero. Therefore

$$\Re = 1 - \frac{(\sqrt{S} - m_{d'})\left(\frac{E}{\sqrt{S}} - 1\right)}{(\sqrt{S} - m_{d'})\frac{E}{\sqrt{S}} - m_t} \to \frac{\sqrt{S}}{E} \quad (\text{when } \sqrt{S} >> m_{d'}, m_t) \tag{2}$$

in the target rest frame (E is full energy). The ratio $\Re$ goes to zero when initial momentum increases to infinity.

Except for the completely inelastic limit, at fixed initial energy and scattering angle (in the target rest frame) the $\Re$ as a function of m_X (or Δm_X) has two branches, which correspond to the «forward» and «backward» (in the center of mass frame) scattering. It is clear that the «forward» value of $\Re$ must be larger than «backward» one at given Δm_X.

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