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COLLECTIVE EXCITATION OF Δ-ISOBAR IN CHARGE EXCHANGE REACTIONS (^{7}Li, ^{7}Be) AND (^{3}H, ^{3}He) AT A PROJECTILE MOMENTUM OF 3 GeV/c PER NUCLEON

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Charge exchange reactions were investigated in nuclear beams at 3 GeV/c per nucleon. The total cross sections of the reactions (^{3}H, ^{3}He) and (^{7}Li, ^{7}Be) were measured for H, C, Al, Cu and Pb target nuclei. For the first time the reaction (^{3}H, ^{3}He) was investigated in 4π-geometry. Our data give testimony to a significant role of collective excitation of the delta isobar in nuclei.

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

Коллективное возбуждение дельта-изобары в реакциях перезарядки (^{7}Li, ^{7}Be) и (^{3}H, ^{3}He) при импульсе 3 ГэВ/с на нуклон

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Исследованы реакции перезарядки (^{3}H, ^{3}He) и (^{7}Li, ^{7}Be) при импульсе 3 ГэВ/с на нуклон в ядерных пучках синхрофазотрона ОИЯИ (Дубна). Полные сечения обеих реакций измерены для мишеней H, C, Al, Cu и Pb. Впервые реакция (^{3}H, ^{3}He) исследована в 4π-геометрии. Получены доказательства существенной роли коллективного возбуждения дельта-изобары в ядрах.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

In several Dubna and Saclay experiments it has been shown that at sufficiently high kinetic energies of the projectile (more than 800 MeV/nucleon) the charge exchange (^{3}He, ^{3}H) cross sections are dominated by the processes of nuclear delta isobar excitations [1,2]. It has been also observed that the width of the Δ peak increases by a factor of two if the target atomic number exceeds 10, but the position of a peak maximum is shifted down to lower Q by a 40 MeV value as compared with hydrogen target data (Q is the energy transferred to the target).

Some attempts to calculate the process as the production of Δ isobar on quasi-free target nucleon failed: it was impossible to reproduce neither the width of the peak nor the position of the maximum. Then the idea of collective interactions of Δ in target nuclei was proposed [1,3]. An alternative mechanism, the excitation of Δ in the projectile was suggested by E.Oset [4]. Nevertheless, to solve the issue, all models and calculations needed more detailed additional data than the inclusive experiments [1,2].

The main goal of our experiment was to investigate characteristics of all charged particles produced in the charge exchange reactions. The experimen was performed using the facility of the streamer chamber spectrometer GIBS. A tritium beam was produced by the fragmentation of a ^{4}He beam (3 GeV/c per nucleon) on a special-purpose target. The beam transport channel was tuned for 9 GeV/c fragments, and the really measured beam parameters were the following: a mean momentum of 9.10 ± 0.06 GeV/c and FWHM about 1 GeV/c. Special test showed that the admixture of background particles in the tritium beam was negligible.

The basic part of the spectrometer was a Ne-filled 2x1x0.6 m^3 streamer chamber in the magnetic field [5,6]. The investigated charge exchange reactions were produced on a magnesium target (60x30 mm^2, 1.56 g/cm^2) installed inside the chamber or on neon gas. The target was placed at a 60 cm distance from the entrance window. Such a position of the target allowed one to register and to measure all charged particles. The streamer chamber was triggered by coincidence of signals from two blocks of scintillation counters. In the first one (upstream the chamber) a beam particle (^{3}H with unit charge) had to be registered. The second block of counters (40×25 cm^2) was tuned to register a particle with charge 2 (^{3}He) and located at a distance 5 m downstream the target where ^{3}He nuclei had to be bent by analyzing magnet. The approach provided a good efficiency (90%) and background suppression.

The total cross sections of the reactions (^{3}H, ^{3}He) and (^{7}Li, ^{7}Be) were measured in special experiments without the streamer chamber, but with the same idea of trigger: to measure the charge Z of the beam nucleus and to detect a charge value of $Z + 1$ of the nucleus after charge

Table 1

N_-	N_+	Number of events charge.exch. Mg(^{3}H, ^{3}He)	Mean transferred momentum (GeV/c)
0	0	673	0.19 ± 0.06
1	0	568	0.37 ± 0.06
1	1	132	0.54 ± 0.07
1	2	24	
1	3	7	
1	4	1	
1	5	0	
0	1	212	0.30 ± 0.07
0	2	52	0.46 ± 0.09
0	3	7	
0	4	1	
2	0	5	
2	1	7	
2	2	2	
total number 1691			

exchange reaction. In these experiments the number of counters in the second block was increased, and a sophisticated «off-line» analysis was used. Therefore $Z + 1$ nuclei were separated quite well, and the systematic errors did not exceed a few per cent. One should pay attention to that in all charge exchange reactions we had registered the nuclei were conserved. More details of all the experiments see in [7, 8, 9]. Further on we present only the results.

Table 1 presents data on the topology of events, i.e., the number (N_-) of negative and positive (N_+) particles produced in the reactions of ^{3}H charge exchange in the magnesium target. The mean values of momentum transferred to the target are presented for more popular topologies.

We could not identify π^+ mesons among protons, but regarding a very strong suppression of π^+ production in the (^{3}H, ^{3}He) charge exchange one could consider that all positive particles produced in the reactions were protons and all negative particles were π^-.

If a single quasi-free target nucleon is involved in the reaction (^{3}H, ^{3}He), one can expect to observe only three topologies: ($0p, 0\pi^-$), ($0p, 1\pi^-$) and ($1p, 1\pi^-$) [4]. Really there were about 20% of events with an unexpected configuration of charged particles. The events with a single proton are of great interest. A 80 MeV mean proton energy and the spectrum testify that the protons are not produced by an evaporating source. Such a charge exchange reaction accompanied by a single proton was predicted in papers [10, 11]. The source of these protons can be the nonmesic discharge of the delta isobar in the target nucleus ($\Delta^0 p \to np$). On the other hand, the nonmesic discharge must produce the topology ($0p, 0\pi^-$) through the reactions ($\Delta^- p \to nn$) and ($\Delta^0 n \to nn$). This topology can be enriched with quasi-elastic charge exchange and with Δ^0 excitation of the quasi-free target nucleon with subsequent decay $\Delta^0 \to n\pi^0$. We have estimated ratios of these two channels in order to extract them and to find out the number of neutral nonmesic discharge events.

The fraction of the quasi-elastic channel can be estimated using the data from [1] with two suggestions:

a) the fraction of quasi-elastic charge exchange is the same in the reactions $C(^3He, {}^3H)$ and $Mg(^3H, {}^3He)$;

b) the fraction of quasi-elastic charge exchange at all angles is proportional to that at 0° for 7—11 GeV/c momentum of ^3He.

The number of events with a neutral pion can be estimated from the isotopic equation for π^- and π^0 channels if one assumes the excitation of delta on quasi-free nucleon of the target neglecting the interference of diagrams [4]. In the experiment we observed 673 events ($0p, 0\pi^-$) which was 250 larger than the estimated total number of events with π^0 and quasi-elastic charge exchange. There exists a high probability that these 250 events are due to the ($\Delta^0 n \to nn$) and ($\Delta^- p \to nn$) reactions.

We have observed very strong correlations between the topology of the reaction and the mean value of transferred energy. The correlation is clearly illustrated in Fig.1a.

A 70 MeV difference of the mean values of transferred momentum of two topologies ($1p, 0\pi^-$) and ($0p, 1\pi^-$) was observed in our experiment (see Table 1). It should be noted that this value is close to the calculated one [10, 11]. So, the process like ($\Delta N \to NN$) can be at least one of the reasons that causes a shift and widening of the Δ peak in the previous experiments [1, 2] (see Fig.1b).

The observed correlation between the mean values of transferred momentum and the number and type of produced particles testifies against any suggestion of cascade-like particle production. Indeed, one can expect a very slow monotonous (proportional to transferred momentum) increase of the multiplicity of particles produced by recoil nucleon in

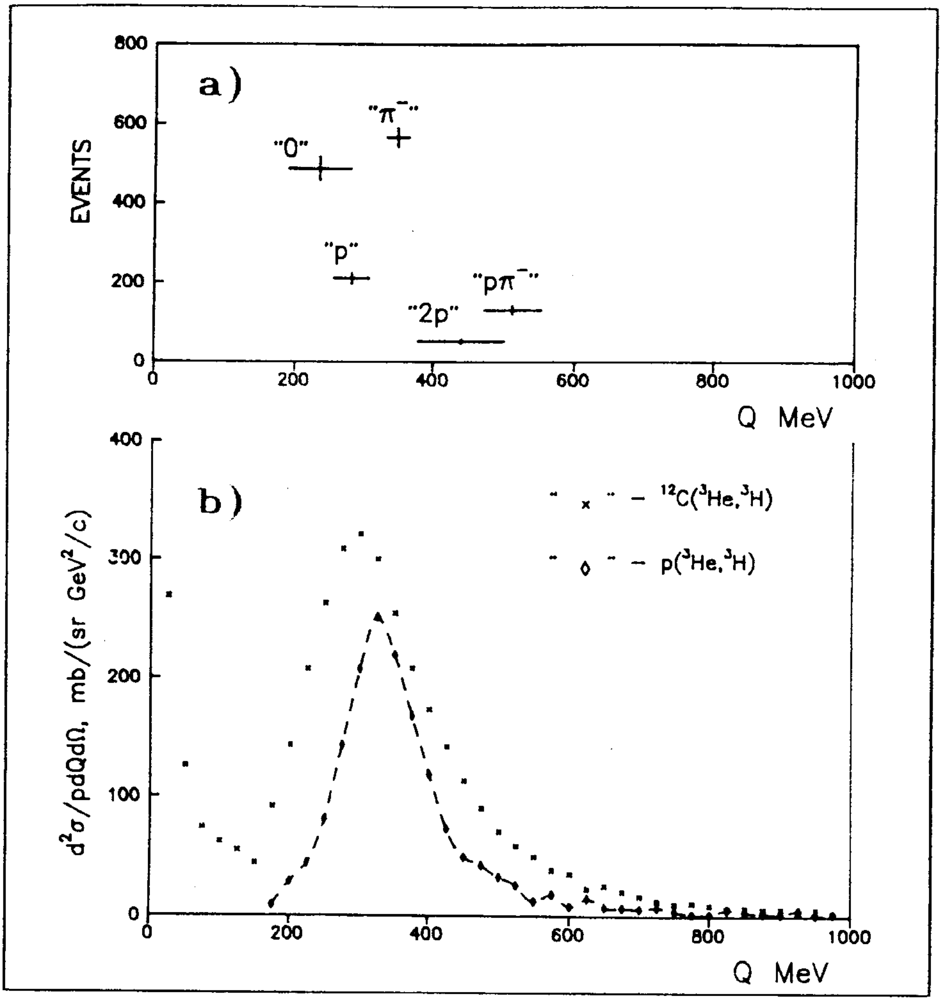


Fig.1. a) Correlation between mean transferred energy Q and topology of charge exchange events (^{3}H, ^{3}He). Notation: «0» — topology ($0p, 0\pi^-$), «π» — topology ($0p, 1\pi^-$), etc. b) The spectra of transferred energy Q for the reactions C(^{3}He, ^{3}H) and p(^{3}He, ^{3}H) at $p_{^3\mathrm{He}}$ = 6.8 GeV/c — data from [1]. The contribution of quasi-elastic events is excluded from the ($0p$, $0\pi^-$) data

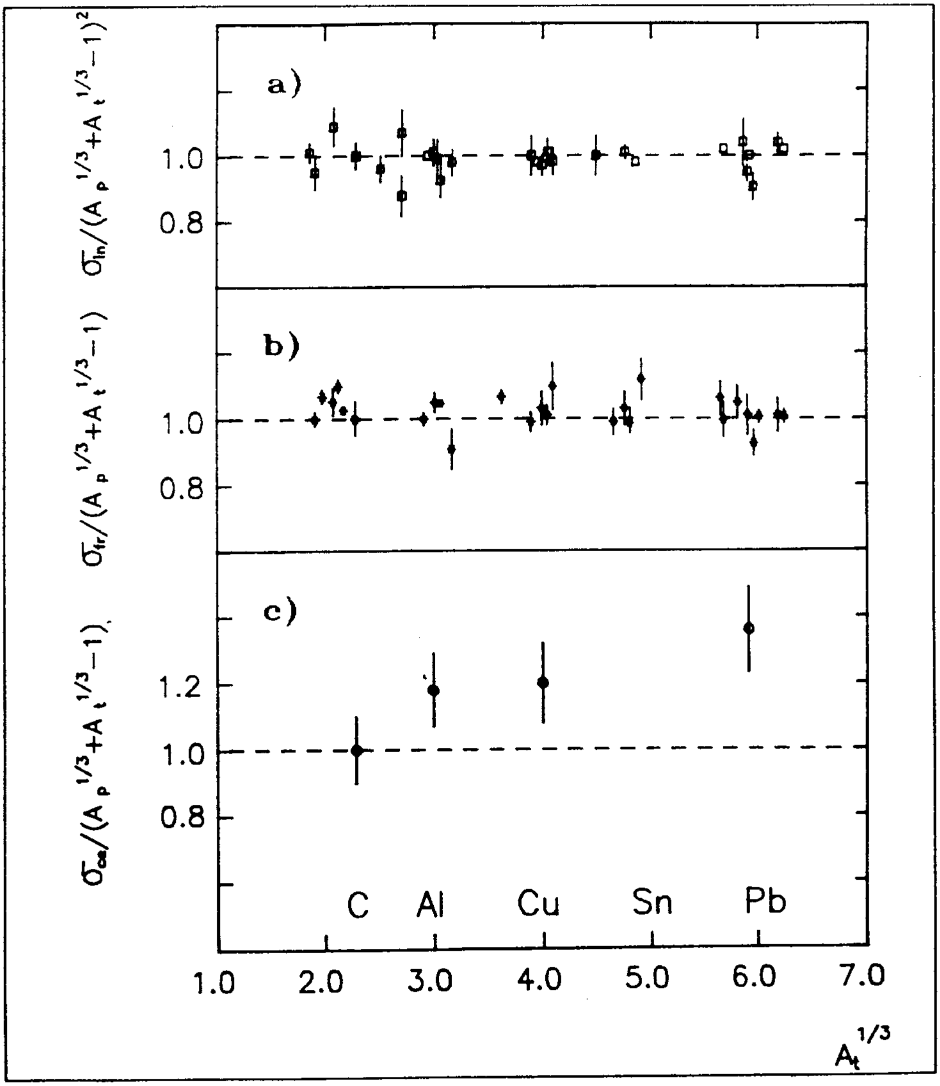
the target contrary to the common (one-step) process of charge exchange and particle production.

The total cross sections for the reactions (^{3}H, ^{3}He) and (^{7}Li,^{7}Be) are concentrated in Table 2. Let us analyse the A-dependence of the cross sections. The total cross sections are described quite well (see Fig.2a) by the formula $\sigma_{in} \sim (A_p^{1/3} + A_t^{1/3} - b)^2$ (A_p, A_t are the atomic mass num-

Table 2

Target	σ_{ce} (mb) (^{7}Li, ^{7}Be)	σ_{ce} (mb) (^{3}H, ^{3}He)
H	0.18 ± 0.05	0.71 ± 0.06
C	0.29 ± 0.03	1.96 ± 0.15
Al	0.42 ± 0.04	2.55 ± 0.20
Cu	0.53 ± 0.05	3.42 ± 0.27
Pb	0.84 ± 0.08	4.88 ± 0.39

Fig.2. a) A-dependence of the inelastic cross section — compilation from the data [12—14]. b) A-dependence of the nuclear fragmentation cross section [13]. c) A-dependence of the charge exchange (^{7}Li, ^{7}Be) cross section. Each cross section is normalized to the corresponsing cross section for the ^{12}C target nucleus



bers of projectile and target nuclei; b, the parameter of overlapping). If one uses this geometrical model for peripheral interactions, then the A-dependence must be $\sigma_{per} \sim (A_p^{1/3} + A_t^{1/3} - b)^2$ with the same value of b. Figure 2b shows that this formula is good enough for typical peripheral reactions — nuclear fragmentation. In all our charge exchange experiments the nucleus had to be conserved to trigger the detector. It means that the transferred momuntum was limited or the impact parameter exceeded a certain minimum value. In other words, the charge exchange reactions in our experiments are peripheral interactions. A significant role of projectile form-factor in the reaction (^{3}He,^{3}H) was also noted in [1]. Therefore one can expect the same A-dependence of the total cross sections in the reactions of fragmentation and charge exchange (^{7}Li, ^{7}Be). As is seen from Fig.2c, they are quite different. We had to introduce the term $A_t^{2/3}$ to fit the data for (^{7}Li, ^{7}Be) as well as for the reaction (^{3}H, ^{3}He) . Recently such a two-component A-dependence was predicted in [10]. The additional term $A_t^{2/3}$ was introduced to describe nonmesic discharge of Δ-isobar.

In conclusion we can say all our data give testimony to that the role of collective excitation of Δ-isobar is significant, i.e., at least several nucleons of the target nucleus are involved in a charge exchange reaction.

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