Collective excitation of Δ isobar in the charge-exchange reactions (^{7}Li,^{7}Be) and (^{3}H,^{3}He) at a momentum of 3 GeV/(c·nucleon)

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(Submitted 6 May 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **55**, No. 12, 676–680 (25 June 1992)

The (^{3}H,^{3}He) reaction at Mg and Ne has been studied in a 4π geometry at a momentum of 3 GeV/(c·nucleon). This is the first such study. The total cross sections for the reactions (^{3}H,^{3}He) and (^{7}Li,^{7}Be) at H, C, Al, Cu, and Pb nuclei have been measured, at the same momentum per nucleon. All the results indicate that effects associated with a collective excitation of a Δ isobar in these nuclei play an important role.

Research on the reaction (^{3}He,^{3}H) and other charge-exchange reactions at momenta of several GeV/(c·nucleon) at Dubna in Russia and Saclay in France has established that a mechanism involving the excitation of a Δ isobar is overwhelmingly predominant in the cross sections for such reactions.[1,2] It has also been pointed out that in charge exchange at nuclei the Δ peak in the energy spectrum of tritium shifts a distance on the order of 40 MeV in the hard direction, and the width of this peak is roughly twice that in the case of charge exchange with free protons.

Attempts have been made to find a theoretical description of the differential cross sections observed under the assumption that a Δ isobar is produced at a quasifree nucleon. These attempts have not been successful. The position of the peak and the width of the resonance part of the spectrum have not been reproduced satisfactorily. It has thus been hypothesized that collective effects associated with a charge exchange

TABLE I.

N_-	N_+	Number of Mg(^3H,^3He) charge-exchange events	Average momentum transfer (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		1691	

with the nuclei play an important role.[1,3] However, it was pointed out in Ref. 4 that the *S*-wave mechanism and the excitation of a Δ isobar in the projectile could in principle also be the reasons for the shift and broadening of the nuclear Δ peak. It has thus not been possible to draw conclusion regarding the nature of the effect which has been seen on the basis of the data available.

The primary distinction between our own studies and studies which have been carried out previously is the exclusive nature of the experiment. This exclusive nature has made it possible to obtain some new and important information.

This study was carried out at the beam of the synchrophasotron of the Joint Institute for Nuclear Research with the help of the GIBS spectrometer. The tritium beam was produced through fragmentation of ^{4}He nuclei, accelerated to 3 GeV/(c·nucleon), at an auxiliary polystyrene target. The average momentum of the ^{3}H nuclei separated out by the channel magnets was 9.10 ± 0.06 GeV/c. The width of the momentum distribution at half-maximum was about 1 GeV/c.

The experimental apparatus is based on a streamer chamber with dimensions of $2.0 \times 1.0 \times 0.6$ m, filled with Ne at atmospheric pressure and immersed in a magnetic field of 0.9 T (Refs. 5 and 6). The Mg target (30×60 mm, 1.56 g/cm^2) is inside the sensitive volume of the chamber.

The total cross sections for the reactions (^{3}H,^{3}He) and (^{7}Li,^{7}Be) were measured by an electronic method using scintillation counters.

The experimental details are given in Refs. 7–9; we restrict the present letter to the basic results.

Table I shows data on the topology of the events, i.e., on the number of particles with negative charge (N_-) and positive charge (N_+) accompanying the charge exchange of ^{3}H with Mg nuclei. Also shown here are values of the average momentum transferred to the target nucleus for the most likely topologies.

Although it is difficult to completely identify the particles in a streamer chamber, the production of π^+ mesons should be greatly suppressed in (^{3}H,^{3}He) charge exchange. We thus assume below that all the negatively charged particles are π^- mesons, while the positively charged ones are protons.

In the case of the reaction (^{3}H,^{3}He) at a quasifree nucleon, one would observe only the topologies[4] ($0p,0\pi^-$), ($0p,1\pi^-$), and ($1p,1\pi^-$). Actually, other sets of charged particles are found in about 20% of the events. One particular group of events which is of considerable interest is that in which the charge exchange is accompanied by the emission of a single proton. The shape of the energy spectrum and the average energy of these protons (about 80 MeV) are clear evidence that these protons are not of evaporation origin. A charge exchange accompanied by the emission of only a proton was predicted in Refs. 10 and 11. The source of these protons is the meson-free decay ($\Delta^0 p \rightarrow np$) of a Δ^0 isobar excited in the target nucleus.

Along with these processes, there should be cases of the interactions ($\Delta^0 n \rightarrow nn$) and ($\Delta^- p \rightarrow nn$). Such events are part of the group with the topology ($0p$, $0\pi^-$). In addition to these events, this topology includes cases of quasielastic charge exchange and events in which a Δ^0 isobar decays in a process involving the production of a π^0 meson. The relative number of events of quasielastic charge exchange can be estimated from the data of Ref. 1 under the following assumptions: (a) The relative numbers of events of quasielastic charge exchange in the reactions C(^{3}He,^{3}H) and Mg(^{3}H,^{3}He) are the same. (b) The relative number of events of quasielastic charge exchange in the ^{3}He momentum interval 7–11 GeV/c, for all angles, is proportional to the relative number of events of quasielastic charge exchange at 0°. If we ignore the interference between diagrams, we can find the number of events with neutral pions from the isotopic ratios between the channels involving the emission of π^0 and π^- mesons under the assumption of a quasifree excitation of a Δ isobar.[4] After we subtract the number of events of quasielastic charge exchange and of charge exchange involving the emission of neutral pions from the total number of events with the topology ($0p$, $0\pi^-$), we are still left with about 250 events. It is extremely probable that these events are caused by the processes ($\Delta^0 n \rightarrow nn$) and ($\Delta^- p \rightarrow nn$).

Figure 1a demonstrates the strong correlation which we have observed between the average energy transfer and the topology of the event. Events of quasielastic charge exchange have been eliminated from the ($0p$, $0\pi^-$) group here. The difference between the average ^{3}He momentum transfer in the topologies ($1p$, $0\pi^-$) and ($0p$, $1\pi^-$), on the order of 70 MeV/c (Table I), agrees with the calculations of Refs. 10 and 11. The processes ($\Delta N \rightarrow NN$) are therefore at least one of the reasons for the broadening and shift of the nuclear Δ peak in the experiments of Refs. 1 and 2 (Fig. 1b).

The correlation between the average momentum transfer and the multiplicity and species of the accompaniment particles indicates that these particles are not produced by a cascade process. If these particles were not produced in the same interaction event

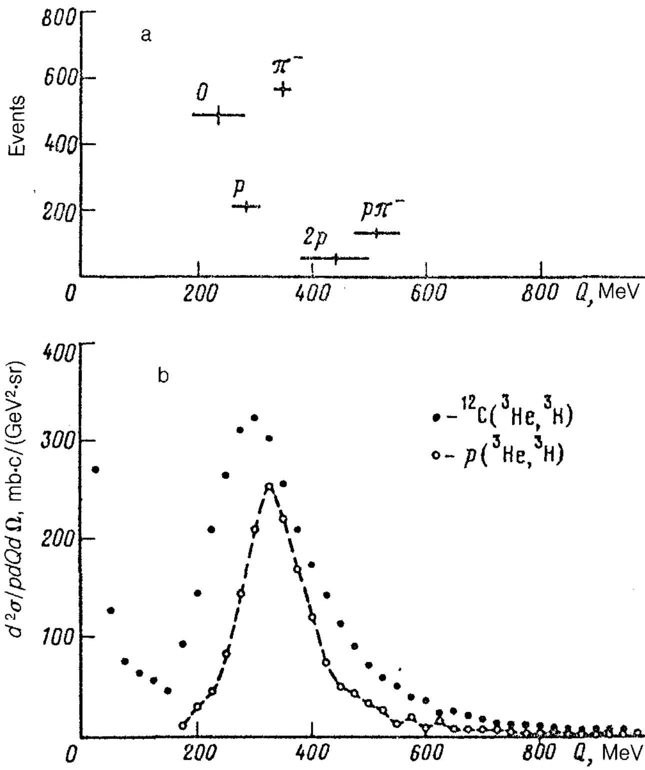

FIG. 1. a: Correlation between the average energy transfer Q and the topology of the (^3H,^3He) charge-exchange events. A 0 represents a group of events with the topology ($0p$, $0\pi^-$), π represents a group with the topology ($0p$, $1\pi^-$), etc. b: Spectra of the energy transfer Q in the reactions C(^3He,^3H) and p(^3He,^3H) at $P_{^3He} = 6.8$ GeV/c, according to the data of Ref. 1.

involving the charge exchange (and were instead produced as the result of a secondary interaction of a recoil nucleon), then only a weak dependence—a monotonic increase—of the multiplicity of the accompaniment particles on the momentum transfer could have been observed. (This dependence would have been a consequence of energy-momentum conservation.)

Table II shows the numerical values of the total cross sections for the reactions

TABLE II.

Target	σ_{ce} (mb) (^7Li, ^7Be)	σ_{ce} (mb) (^3H, ^3He)
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

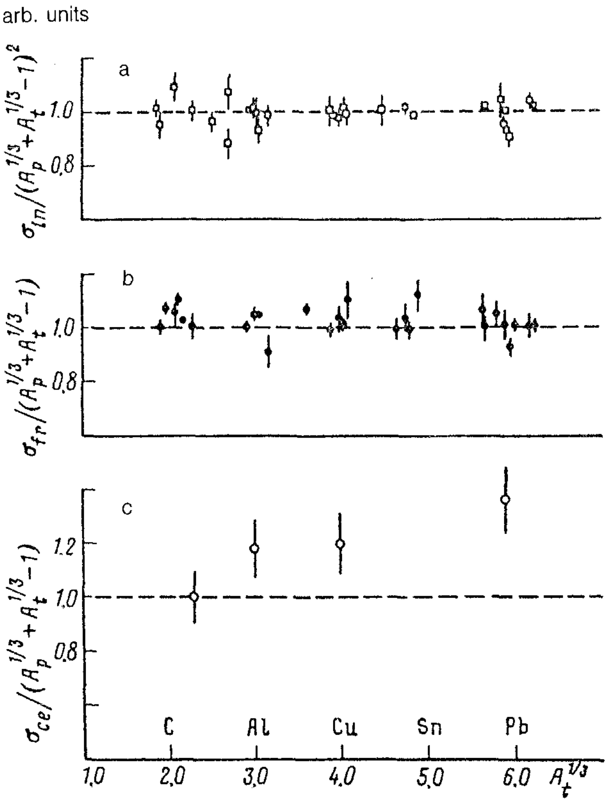

FIG. 2. a—A dependence of the cross sections for inelastic interactions for various nuclei according to the data of Refs. 12–14; b—A dependence of the fragmentation cross sections according to the data of Ref. 13; c—A dependence of the cross sections for the charge exchange (^{7}Li,^{7}Be).

(^{3}H,^{3}He) and (^{7}Li,^{7}Be) according to our measurements.

The A dependence of these cross sections requires a special analysis. The total cross sections for inelastic nucleus–nucleus interactions can be described satisfactorily by the formula $\sigma_{in} \propto (A_p^{1/3} + A_t^{1/3} - b)^2$ (Fig. 2a). According to this geometric model, we would naturally suggest an A dependence $\sigma_{per} \propto (A_p^{1/3} + A_t^{1/3} - b)$ for peripheral reactions, with the same value of the overlap parameter b. Figure 2b shows that this is indeed the case, at least for fragmentation reactions. In our case, the requirement that the nucleus which has undergone charge exchange be preserved as a whole imposes an upper limit on the momentum transfer (or a lower limit on the impact parameter) in the charge-exchange process. Ableev *et al.*,[1] for example, have pointed out the important role played by the form factor of the projectile for the (^{3}He,^{3}H) reaction. In other words, the charge exchange must occur at the periphery of the nucleus. On the basis of these considerations we would expect the total cross sections for the (^{7}Li,^{7}Be) process to behave in the same way as those for fragmentation reactions. This is not what we find (Fig. 2c). In order to fit the experimental data it was necessary to introduce an additional term $\propto A_t^{2/3}$. A similar picture is observed for the A dependence of the total cross sections for the reaction (^3H,^3He).

This effect was also predicted in Ref. 10. It is the meson-free decay of the Δ isobar which is responsible for the $\propto A_t^{2/3}$ term.

In summary, all our data point to an important role for effects associated with the collective excitation of a Δ isobar. In other words, several nucleons of the nucleus are involved in the charge-exchange reaction.

We wish to thank F. A. Gareev, Yu. L. Ratis, S. M. Eliseev, V. I. Inozemtsev, and E. A. Strokovskiĭ for valuable discussions and useful comments.

[1]V. G. Ableev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **40**, 35 (1984) [JETP Lett. **40**, 763 (1984)].
[2]D. Contardo *et al.*, Phys. Lett. B **168**, 331 (1986).
[3]V. Dmitriev *et al.*, Nucl. Phys. A **459**, 503 (1986).
[4]E. Oset *et al.*, Phys. Lett. B **224**, 249 (1989).
[5]S. N. Bazylev *et al.*, P10-90-533, Joint Institute for Nuclear Research, Dubna, 1990.
[6]Yu. A. Belikov *et al.*, P1-91-209, Joint Institute for Nuclear Research, Dubna, 1991.
[7]S. A. Avramenko *et al.*, P1-91-206, Joint Institute for Nuclear Research, Dubna, 1991.
[8]S. A. Avramenko *et al.*, P1-91-239, Joint Institute for Nuclear Research, Dubna, 1991.
[9]S. A. Avramenko *et al.*, P1-91-240, Joint Institute for Nuclear Research, Dubna, 1991.
[10]F. A. Gareev and Yu. L. Ratis, P2-89-805, Joint Institute for Nuclear Research, Dubna, 1989.
[11]F. Gareev and Yu. Ratis, JINR E2-89-876, Dubna, 1989.
[12]V. D. Aksinenko *et al.*, Nucl. Phys. A **348**, 518 (1980).
[13]G. D. Westfall *et al.*, Phys. Rev. C **19**, 1309 (1979).
[14]V. M. Golovin *et al.*, P1-88-175, Joint Institute for Nuclear Research, Dubna, 1988.

Translated by D. Parsons