Double inelastic charge exchange in interactions of 50-GeV/c π^- mesons with nucleons and with light (CNO) and heavy (AgBr) emulsion nuclei; comparison with the constituent quark model

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Experimental data are reported on double inelastic charge exchange, defined as the ratio of (a) the number of events in which the secondary particle having the maximum momentum has a charge sign differing by two from that of the incident particle to (b) the number of events in which the secondary particle with the maximum momentum has the same charge sign as the incident particle. The results found for the interaction of 50-GeV/c π^- mesons with nucleons, light emulsion nuclei (CNO), and heavy emulsion nuclei (AgBr) are compared with calculations from the constituent-quark model. There is a satisfactory agreement.

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We have studied the probability for double inelastic charge exchange in the interactions of π^- mesons with nucleons and light and heavy nuclei of a photographic emulsion which was bombarded on the Serpukhov accelerator at an energy of 50 GeV in a pulsed magnetic field. This experimental procedure reliably yields the sign of the charge of the secondary particle and allows momentum measurements within 10–15%.

The criteria used for classifying interactions with the emulsion nuclei as interactions with nucleons, interactions with light nuclei (CNO), and interactions with heavy nuclei (AgBr) are specified in detail elsewhere.[1]

For each interaction we determined the following: n_s, the number of relativistic particles ($\beta > 0.7, J < 1.4\,J_0$); n_g, the number of "gray" tracks ($\beta \leqslant 0.7, J \geqslant 1.4\,J_0$, 30 MeV $\leqslant E_p \leqslant$ 400 MeV); n_b, the number of "black" tracks or the tracks of nuclear evaporation particles ($E_p < 30$ MeV); and the sum $n_h = n_g + n_b$. Here J_0 is the minimum ionization, and β and E are the velocity and energy of the particle.

All the interactions were then classified in one of four groups: 1) πN interactions with free and quasifree emulsion nuclei (coherent interactions were eliminated); 2) the group L, representing pA interactions with $1 \leqslant n_h \leqslant 6$ and with a minimum range $R_{\min} \leqslant 80$ μm for the black track [this group makes up ~70% of the interactions with the CNO nuclei]; 3) the group H_1, representing pA interactions with $1 \leqslant n_h \leqslant 6$ and $R_{\min} > 80$ μm; 4) the group H_2, representing pA interactions with $n_h \geqslant 7$. The events in groups H_1 and H_2 are identified as interactions with heavy nuclei (AgBr) and amount to, respectively, ~40% and ~50% of all the interactions with this group of nuclei.

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To find the characteristics of the interactions with the CNO and AgBr nuclei, the L and $H_1 + H_2$ groups were supplemented with events from the πN interactions in accordance with the geometric cross sections (we used $\sigma \sim A^{0.75}$).

We assumed that in a given interaction the incident π^- meson underwent double inelastic charge exchange if the secondary particle having the maximum momentum had a charge sign differing from that of the primary particle by 2, i.e., if it was positively charged in the present case (such events are designated $\pi^- \to h^+$). In events in which inelastic charge exchange did not occur, the secondary particle having the maximum momentum had the charge of the same sign as that of the incident particle, i.e., was negatively charged in the present case ($\pi^- \to h^-$).

Shabel'skiĭ[2] has calculated $R(\pi^-) = N_{\pi^- \to h^+}/N_{\pi^- \to h^-}$ the ratio of the number of events involving double inelastic charge exchange to the number of events not involving charge exchange for a primary π^- meson, as a function of the atomic number of the nucleus. He used the constituent-quark model, which assumes that the hadrons consist of two constituent quarks (in the case of mesons) or three (in the case of baryons). A collision with a nucleon involves an interaction of only one pair of quarks: one from the incident particle and one from the target. The remaining quark (in the case of an incident meson, as in our experiments) is a passive spectator quark, retaining its momentum, which is equal on the average to half the momentum of the incident meson. In a collision with a nucleus, there is another possibility: In addition to a reaction analogous to the meson–nucleon reaction, in which only a single pair of quarks interacts, there may be reactions in which both quarks of the incident meson interact inelastically. The probability for reactions with a multiple interaction of quarks increases with increasing atomic number of the target nucleus.

The most energetic secondary particles are formed from a spectator quark and from a quark picked up from the "sea." In the case of an incident π^- meson, the leading particle formed in this manner may be primarily either a π^- or π^0 meson, for which $\langle P_\pi \rangle = \langle P_q \rangle = 1/2 \cdot P_0$. Furthermore, the spectator quark may convert into a ρ^-, ρ^0, or ω^0 meson, in which case the π mesons produced in the decay of these other mesons will have average momenta of $\langle P_\pi \rangle = 1/2 \langle P_q \rangle = 1/4 \cdot P_0$ or $\langle P_\pi \rangle = 1/3 \langle P_q \rangle = 1/6 \cdot P_0$, respectively. The leading particle cannot be a π^+ or ρ^+ meson, since these particles have no constituent quarks in common with the π^- meson.

To calculate the ratio $R(\pi^-)$, Shabel'skiĭ[2] used the following equations relating the leading-particle multiplicities, derived from the quark combinatorial rules:

$$\langle N^f_{\pi^-} \rangle = 2 \langle N^f_{\pi^0} \rangle,$$

$$\langle N^f_{\rho^-} \rangle = 2 \langle N^f_{\rho^0} \rangle),$$

$$\langle N^f_{\rho^0} \rangle = \langle N^f_{\omega^0} \rangle .$$

For the comparison with the results of the present experiments, the ratio $r = \langle N_{\rho^-} \rangle / \langle N_{\pi^-} \rangle = \langle N_{\rho 0} \rangle / \langle N_{\pi 0} \rangle$ was taken to be 1 or 3; the value $r = 3$ arises when we incorporate the spin of the ρ meson. The contribution of K mesons was ignored. Working from the equations of Ref. 2, we then find the following approximate expression for the ratio R for $\pi^- N$ interactions:

$$R(\pi^-) = \frac{N_{\pi^- \to h^+}}{N_{\pi^- \to h^-}} \approx \frac{(0{,}5 < N_{\rho^0} > + 0{,}3 < N_{\omega^0} >) : < N_\Sigma >}{(< N_{\pi^-} > + 0{,}5 < N_{\rho^-} > + 0.5 < N_{\rho^0} > + 0.3 < N_{\omega^0} >) : < N_\Sigma >}, \quad (1)$$

where $\langle N_\Sigma \rangle$ is the resultant average multiplicity of all leading particles. We find $R(\pi^-) = 0.11/0.54 = 0.21$ for $r = 1$ and $R(\pi^-) = 0.16/0.49 = 0.33$ for $r = 3$. For π^-–nucleus interactions, we find

$$R(\pi^-) = \frac{0{,}11 \cdot V_1 + 0{,}3 \cdot V_2}{0.54 \cdot V_1 + 0{,}3 \cdot V_2} \quad \text{for } r = 1, \quad (2)$$

$$R(\pi^-) = \frac{0.16 \cdot V_1 + 0{,}3 \cdot V_2}{0{,}49 \cdot V_1 + 0.3 \cdot V_2} \quad \text{for } r = 3, \quad (3)$$

where V_1 and V_2 are the probabilities for one and two constituent quarks, respectively, to interact with the nucleus; the probabilities depend on the atomic number of the target nucleus.

The values of the ratio $R(\pi^-) = N_{\pi^- \to h^+}/N_{\pi^- \to h^-}$ found experimentally for nucleons and for the groups of nuclei CNO and AgBr are shown in Fig. 1; also shown here, by the solid curves, are the results calculated for R as a function of A from Eqs. (1)-(3). There is a qualitative agreement between the experimental and calculated results. The experimental data indicate that the ratio $r = \langle N_{\rho^-} \rangle / \langle N_{\pi^-} \rangle = \langle N_{\rho}0 \rangle / \langle N_{\pi}0 \rangle$ is more likely one than three.

Figure 2 shows the experimental results on the dependence of the ratio $R(\pi^-)$ on

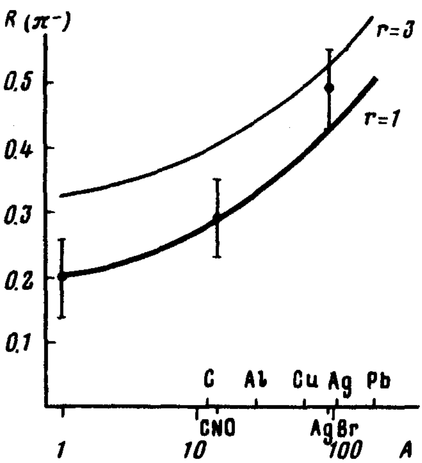

FIG. 1. Dependence of the ratio $R(\pi^-) = N_{\pi^- \to h^+}/N_{\pi^- \to h^-}$ on the atomic number of the target nucleus for the interactions of π^- mesons with a momentum of 50 GeV/c. The curves show results calculated from the additive quark-parton model[2] for values of one and three for the ratio $r = \langle N_{\rho^-} \rangle / \langle N_{\pi^-} \rangle \langle N_{\rho}0 \rangle / \langle N_{\pi}0 \rangle$.

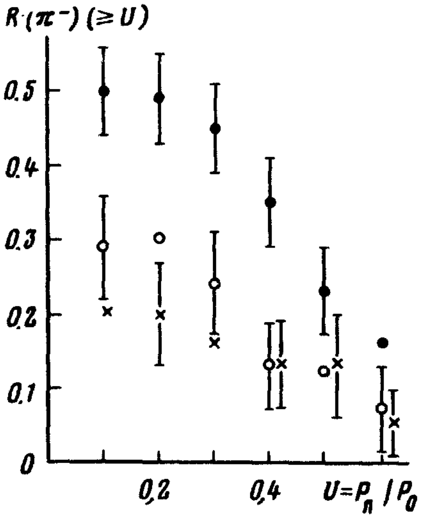

FIG. 2. Dependence of the ratio $R(\pi^-) = N_{\pi^- \to h^+}/N_{\pi^- \to h^-}$ on $U = P_L/P_0$ for the interactions of 50-GeV/c π^- mesons with various particles. ×—With nucleons; ○—with light emulsion nuclei (CNO); ●—with heavy emulsion nuclei (AgBr).

P_L/P_0 for the interactions of π^- mesons with nucleons, with the CNO nuclei, and with the AgBr nuclei. In plotting these results we required that the maximum momentum of the secondary particle in the interaction be greater than the given value of P_L/P_0. These results are again in qualitative agreement with the predictions of the constituent-quark model, which makes the following predictions. On the one hand (as can be seen from Fig. 1), the ratio $R(\pi^-)$ must increase with increasing atomic number of the target nucleus. On the other, since there are no "direct" leading π^+ mesons, the ratio $R(\pi^-)$ must approach zero at sufficiently large values of P_L/P_0, where the particles from the decay of ρ and ω mesons are of negligible importance.

In summary, for the interactions of π^- mesons with emulsion nuclei at 50 GeV, the following values have been found for the ratio $R(\pi^-) = N_{\pi^- \to h^+}/N_{\pi^- \to h^-}$, which is a measure of the double inelastic charge exchange of a π^- meson into a π^+ meson: 0.20 ± 0.06, 0.29 ± 0.06, and 0.49 ± 0.06 for quasinucleon interactions, for interactions with light nuclei (CNO), and for interactions with heavy nuclei (AgBr), respectively.

These results agree with calculations from the constituent-quark model[2] based on the following relationships between the multiplicities of the secondary particles which include a spectator quark:

$$\langle N^f_{\pi^-} \rangle = 2 \langle N^f_{\pi^0} \rangle = \langle N^f_{\rho^-} \rangle,$$
$$\langle N^f_{\rho^-} \rangle = 2 \langle N^f_{\rho^0} \rangle = 2 \langle N^f_{\omega^0} \rangle.$$

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2. Yu. M. Shabel'skiĭ, Preprint No. 610, Leningrad Insitute of Nuclear Physics, Leningrad, 1980.

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