Excitation of Δ isobars in single pion charge exchange at 1 GeV

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A peak corresponding to a nuclear excitation energy of about 300 MeV has been discovered in the spectra of π^0 mesons from the (π^-, π^0) reaction with carbon and aluminum nuclei at an angle of 10°. This peak is interpreted as a manifestation of a Δ_{33} isobar in the nucleus. It lies at an excitation energy lower than that for the (π^+, π^0) reaction with a free proton.

Recent experiments on charge-exchange reactions at nuclei at intermediate and high energies have revealed a nuclear excitation with an energy of about 300 MeV, which corresponds to the energy of an intense baryon resonance, Δ(1232), with a spin $S = 3/2$ and an isospin $T = 3/2$. These studies have attracted interest because the properties of the resonance are quite different from those in the case of a free isobar. One might therefore raise the question of a change in the properties of the Δ resonance in nuclear matter or the observation of some unusual nuclear excitation. The first studies of charge exchange involving the excitation of the Δ isobar in nuclei were

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carried out with nucleons: the (p,n) reaction,[1] reactions with light nuclei[2-4] (^{3}He, T), reactions with electrons,[5] and reactions with relativistic heavy ions.[6]

Research on the excitation of Δ-isobar resonances in nuclei in the pion charge-exchange reaction $(\pi^{\pm},\pi^0)$, is of further interest because the reaction mechanism, primarily the exchange of a ρ meson, makes it possible to compare the change in charge in beams of negative and positive pions, and there are no Δ excitations in the incident particle. However, the first study, carried out at a pion beam energy of 475 MeV, failed to reveal a peak corresponding to a Δ-isobar resonance near the threshold.[7]

Some conclusions about the nature of the distinctive features of this reaction can be drawn from the form of the elementary amplitude for the πN interaction:

$$f_{\pi N} = (f_{00} + f_{01}\,\mathbf{t}\vec{\tau}) + i\sin\theta\,\vec{\sigma}\,\mathbf{n}(f_{10} + f_{11}\,\mathbf{t}\vec{\tau}), \quad (1)$$

where f_{ST} are the spin–isospin amplitudes; θ is the pion scattering angle in the c.m. frame; $\vec{\tau}$, $\mathbf{t}$, and $\vec{\sigma}$ are the operators representing the isospin of the pion and the isospin and spin of the nucleon; and $\mathbf{n}$ is a unit vector oriented perpendicular to the plane of the reaction. It follows that the cross section for the process with excitation of the Δ isobar vanishes at $\theta = 0°$, since it is determined by the amplitude f_{11}, in contrast with charge exchange involving nucleons, in which spin–spin forces are predominant, and the cross section reaches its maximum at an angle of 0°. At low energies, the amplitude f_{00} is predominant. As the energy is increased, however, the amplitude f_{11} becomes relatively more important, and we can expect the peak corresponding to the Δ excitation to increase with respect to the multiple background processes which form the smooth pedestal of the resonance.

The role played by the surface of the nucleus can be evaluated in the eikonal approximation, which is valid at sufficiently high pion energies.[8] When the factor of $\sin\theta$ is taken into account in the interaction amplitude, (1), the cross section has a characteristic angular dependence with a peak at a certain reaction angle which decreases with increasing initial energy. In our case, at a momentum of 1.1 GeV/c of the incident pion, the peak is at $\theta = 10°$.

Measurements were carried out in the pion beam of the magnetic channel of the Kaspiĭ installation of the Institute of Nuclear Research, Academy of Sciences of the USSR, in the extracted beam of the synchrophasotron of the High Energy Laboratory of the Joint Institute for Nuclear Research. A beam of positive and negative pions with momenta from 0.6 to 1.2 GeV/c, with an intensity up to 5×10^5 pions over the working cycle of the accelerator, was used for calibration and for the actual measurements. The targets of polyethylene, graphite, and aluminum ranged in thickness from 2 to 6 g/cm^2. The spectra of π^0 mesons were measured through the detection of their decay into two γ rays by blocks of lead-glass Čerenkov detectors in a horizontal plane, with six counters in each block, 10×10 cm in size, with a thickness of 14 radiation lengths. The reaction angle was varied by rotating the plane of the detectors around a fixed center at the target, with a capture angle of about $\pm 2°$. The geometric efficiency of the apparatus was about 0.8 msr and was found both by calculations and through a calibration of the apparatus on the basis of the known cross sections for the reaction $\pi^- p \to \pi^0 n$ at various momenta of the π^- mesons.

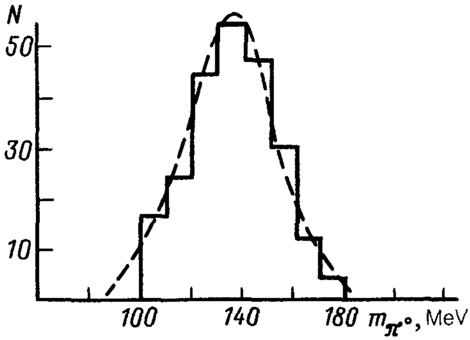

FIG. 1. Invariant-mass spectrum of the π^0 mesons. The average value of the mass is 138 ± 16 MeV; the initial momentum of the π^+ mesons is 1.2 GeV/c.

Figure 1 shows the invariant-mass spectrum of the two decay γ rays, determined from the energies of these γ rays, which were released in the Čerenkov counters, and from the emission angle with respect to the centers of the surfaces of the counters. We see that the neutral pions can be distinguished reliably.

Figure 2 shows spectra of π^0 mesons found during the charge exchange of π^+ and π^- mesons with hydrogen nuclei and of π^- mesons with carbon and aluminum nuclei, for an incident-pion momentum of 1.1 GeV/c and a reaction angle 10° in the laboratory frame. We see that the spectral peak for the reaction $\pi^- p \to \pi^0 n$ at a total

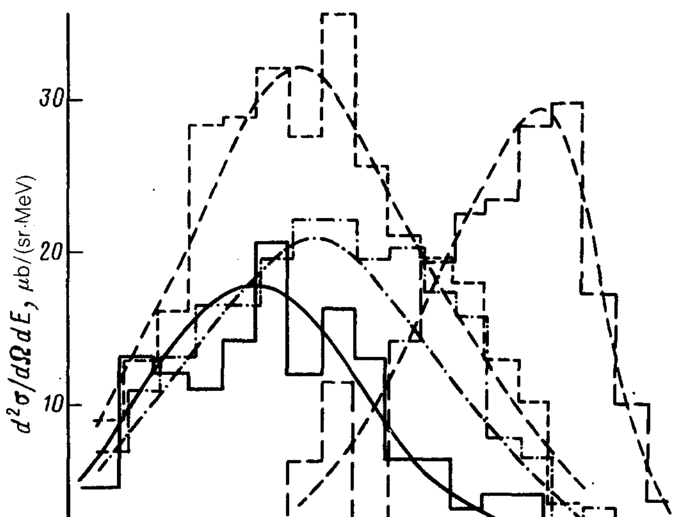

FIG. 2. Dashed curve—Spectrum of the total energies of π^0 mesons from the (π^-,π^0) reaction with hydrogen nuclei; dot–dashed curve—the same, for carbon nuclei; dashed lines—the same, for aluminum nuclei; solid curve ($\times 2$)—from the (π^-,π^0) reaction at hydrogen nuclei. The momentum of the $\pi^\pm$ mesons is 1.1 GeV/c; the π^0 mesons are emitted at an angle of 10°.

energy of 1130 ± 10 MeV of the π^0 mesons agrees fairly well with the value expected on the basis of the momentum of the primary beam, 1102 ± 10 MeV. The positions if the peaks in the spectra were determined through an approximation by Gaussians. The peak in the spectrum of π^0 mesons in the interaction of positive pions with hydrogen nuclei at 785 ± 20 MeV results from the reaction channel $\pi^+ p \rightarrow \pi^0 \Delta^{++}$. The process $\pi^- p \rightarrow \pi^0 \Delta^0$ is not observed at the background level. However, estimates based on isotopic invariance show that the cross section for this process ranges from 3% to 40% of the observed reaction involving the excitation of the Δ^{++} isobar, depending on the relative importance of the channels with isospins of 3/2 and 1/2.

In the spectra of the (π^-, π^0) reaction at the nuclei we see peaks at an energy of 845 ± 10 MeV for the graphite target and 840 ± 10 MeV for the aluminum. These peaks are shifted about 50 MeV down the excitation-energy scale from the quasielastic excitation of the Δ isobar in the reaction with hydrogen. The magnitude and direction of this shift of the resonance agree approximately with the results found in a study of the (^{3}He, T) reaction at nuclei and hydrogen.[2-4] Although the mechanisms for the (^{3}He, T) and $(\pi^\pm, \pi^0)$ reactions at nuclei are different, as has been pointed out, all the data are consistent with the interpretation of the excitation of bound Δ-daughter states in nuclei with a binding energy of several tens of MeV. Among other explanations of the shift of the resonance we might mention the possibility of an influence of cluster effects in nuclei, leading to a kinematic shift of the quasielastic peak.[9]

If we assume that the nuclei contain some extremely narrow and shifted collective Δ resonances, which are probably observed in pion production,[10] we could suggest that the peaks observed in the spectrum of π^0 mesons at nuclei actually consist of two peaks: a wide, quasifree peak due to multiple interactions of pions with nucleons of the nucleus and a narrower Δ state, shifted toward large energies of the π^0 mesons. This process would draw the picture observed in these experiments.

We note that in Fig. 2 there is no excitation of low-lying states in the nuclei in the (π^-, π^0) reaction. We know that an excitation of isobar-analog states in nuclei has been observed in the (π^+, π^0) reaction at pion energies of abut 200 MeV (Ref. 11). States of this sort cannot be excited in a (π^-, π^0) reaction. It was also mentioned in Ref. 3 that the cross section for the excitation of the low-lying states in the (^{3}He, T) reaction decreases with increasing energy.

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