Production of strange particles by a neutral current and the quark hypothesis

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It is shown that in $SU(4)$ symmetry one can expect an increased number of strange particles in processes in which neutral current takes part.

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One of the puzzling problems of the physics of weak interactions is the absence of strangeness-nonconserving neutral currents. An interesting hypothesis was advanced in[1], namely that this may be a manifestation of $SU(4)$ symmetry of weak interactions. We shall show here that the presence of $SU(4)$ symmetry leads to an increased production of strange particles by a neutral current. The Hamiltonian of the weak interaction of quarks with leptons is of the form[2]

$$H = \frac{G}{\sqrt{2}}\{\bar{\mu}\gamma_\mu(1+\gamma_5)\nu[\bar{u}\gamma_\mu(1+\gamma_5)(d\cos\theta + s\sin\theta) + \bar{c}\gamma_\mu(1+\gamma_5)(s\cos\theta - d\sin\theta)] + \text{h.c.}\} + \frac{G}{2\sqrt{2}}\bar{\nu}\gamma_\mu(1+\gamma_5)\nu\{\bar{c}\gamma_\mu(1+\gamma_5)c + \bar{u}\gamma_\mu(1+\gamma_5)u - \bar{d}\gamma_\mu(1+\gamma_5)d - \bar{s}\gamma_\mu(1+\gamma_5)s - 4\sin^2\alpha J_\mu^{\text{em}}\}. \quad (1)$$

Here, following Feynman, we have introduced the symbols u, d, and s for the ordinary quarks, c for the fourth quark, and j^{em} for the electromagnetic current:

$$j_\mu^{\text{em}} = \frac{2}{3}[\bar{c}\gamma_\mu c + \bar{u}\gamma_\mu u] - \frac{1}{3}[\bar{s}\gamma_\mu s + \bar{d}\gamma_\mu d] \quad (2)$$

θ is the Cabibbo angle and α is the Weinberg angle.

For an analysis of the scattering of leptons by hadrons, we use the model of nonrelativistic quarks, which has made it possible to describe the semileptonic hadron decays (see, e.g., [3]) and the scattering of high-energy hadrons[4] in accord with experiment. We consider first the production of strange particles in two-particle reactions as a result of the charged current. We are interested here only in processes in which strangeness is conserved

$$\nu n \to \mu^- K^+ \lambda(\Sigma_0, \Sigma^0_\delta), \qquad \nu p \to \mu - K^+ \Sigma^+(\Sigma^+_\delta).$$

These processes are described by an annihilation quark diagram of the type of Fig. 1.

Processes of the type $\nu n \to \mu^- K^0 \Sigma^+(\Sigma^+_\delta)$ are forbidden in such a picture, since there are no antiquarks in the nucleon. For antineutrino scattering, the processes $\nu p \to \mu^+ K^0 \lambda(\Sigma^0, \Sigma^0_\delta)$ are allowed and $\bar{\nu} p \to \mu^+ K^+ \Sigma^-(\Sigma^-_\delta)$ are forbidden.

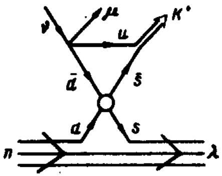

FIG. 1.

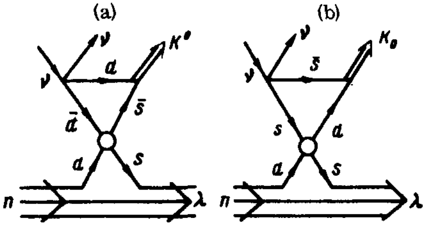

FIG. 2.

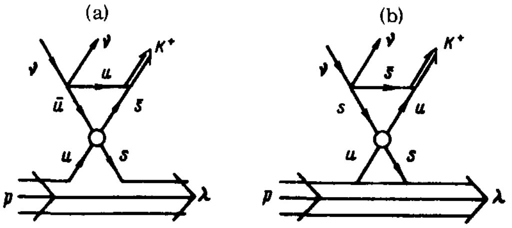

FIG. 3.

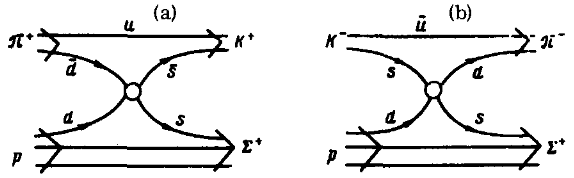

FIG. 4.

In the case of strange-particle production by a neutral current one expects two important differences from the processes that are caused by a charged current:

1. More processes are allowed. For example, in the case of a charged current, the reactions $\nu n \to \mu^- K^0 \Sigma^+ (\Sigma^+_6)$ are forbidden, whereas for a neutral current the process with the presence of K^0 in the final state should take place, etc.

2. The production of strange particles by a neutral current are apparently enhanced in comparison with the charged current. A contribution is made here by two quark diagrams. By way of example, Figs. 2 and 3 show quark diagrams from the processes $\nu n \to \nu K^0 \lambda$ and $\nu p \to \nu K^+ \lambda$.

We introduce for the ratio of the quark amplitudes the notation $(ds \to sd)/(d\bar{d} \to s\bar{s}) = r \exp(i\beta)$. Then, using (1) and isotopic symmetry, we obtain

$$\frac{\sigma(\nu n \to \nu K^0 \lambda)}{\sigma(\nu n \to \mu^- K^+ \lambda)} = \frac{1 + r^2 + 2r\cos\beta}{4}, \tag{3}$$

$$\frac{\sigma(\nu p \to \nu K^+ \lambda)}{\sigma(\nu n \to \mu^- K^+ \lambda)} = \frac{1 + r^2 - 2r\cos\beta}{4}. \tag{4}$$

Allowance for the Weinberg mixing angle decreases the contribution of the neutral vector current. For a rough estimate, we neglect this effect. The quantities r and $\cos\beta$ can in principle be obtained by studying the reactions $\nu n \to \mu^- \pi^0 p$, $\nu n \to \nu \pi^- p$, etc., assuming $SU(3)$ symmetry. In essence, in the discussion of processes with production of strange particles, we used the octet dominance in the t-channel, which is automatically satisfied in the quark model (t is the square of the momentum transferred between the initial and final nucleons). In view of the absence of the necessary experimental data, we determine r from hadron scattering—from the ratio of the cross sections of the reactions $\pi^+ p \to K^+ \Sigma^-$ and $K^- p \to \pi^- \Sigma^+$. These reactions are described by quark diagrams[4] of Fig. 4.

In experiment, in a wide range of energies we have $(K^- p \to \pi^- \Sigma^+)/\sigma(\pi^+ p \to K^+ \Sigma^+) \approx 2$.[5] It follows therefore that $r^2 = 2$, i.e., the diagrams that are typical of the neutral current (2b or 3b) are larger in magnitude than the diagrams analogous to the contribution of the charge current (2a, 3a)!

If the exchange-degeneracy hypothesis were valid, then we would expect $r^2 = 1$ and $\cos\beta = \pm 1$). It is possible that the large value $r^2 = 2$ is responsible for the increased number of charged particles observed in[6]. For example, at $r^2 = 2$ and $\cos\beta = 1$ we have

$$\frac{\sigma(\nu n \to \nu K^0 \lambda)}{\sigma(\nu n \to \mu^- K^+ \lambda)} \approx 1.5, \quad \frac{\sigma(\nu n \to \nu K^0 \lambda) + \sigma(\nu p \to \nu K^+ \lambda)}{2\sigma(\nu n \to \mu^- K^+ \lambda)} = 0.75 \tag{5}$$

Experiment yields for the right-hand side of (5) the value 1.5 ± 1.5.[6]

In conclusion, the author considers it his pleasant duty to thank the participants of the theoretical seminar of the Leningrad Institute of Nuclear Physics for a discussion of the results of the work.

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