The author is deeply grateful to Professor S. A. Al'tshuler for his continuous direction of this work.

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VIOLATION OF THE ΔQ = ΔS RULE IN LEPTONIC DECAYS OF K MESONS AND THE HIGH-ENERGY BEHAVIOR OF WEAK INTERACTIONS

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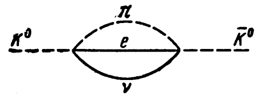
Submitted to JETP editor February 28, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 1411-1413 (May, 1962)

THE recently published experimental data [1] indicate that the ΔQ = ΔS rule is violated in the leptonic decays of K^0 mesons. Namely, in addition to the decay mode $K^0 \to \pi^- + e^+ + \nu$, which is allowed by the ΔQ = ΔS rule, one also has the mode $K^0 \to \pi^+ + e^- + \bar{\nu}$, with the probabilities for the two types of decay approximately equal. It follows from the existence of both types of decay for the K^0 that also the $\bar{K}^0$ can decay in two ways: $\bar{K}^0 \to \pi^+ + e^- + \bar{\nu}$ and $\bar{K}^0 \to \pi^- + e^+ + \nu$, with the consequence that the transition $K^0 \to \bar{K}^0$ can proceed via the chain of interactions $K^0 \to \pi^- + e^+ + \nu \to \bar{K}^0$ or $K^0 \to \pi^+ + e^- + \bar{\nu} \to \bar{K}^0$.

Let us estimate the matrix element for the transition $K^0 \to \bar{K}^0$ due to these interactions by considering the diagram pictured. In this estimate we assume [2] that the weak leptonic interaction preserves its form up to momenta of the order of Λ, i.e., that the integration over the lepton momenta is to be cut off at Λ. (If it is assumed that the form of the weak leptonic interactions changes when energies are reached such that the weak interaction becomes effectively strong, then $\Lambda \sim G^{-1/2} \sim 300$ BeV, where G



$= 10^{-5}/m^2$ is the weak-interaction coupling constant.)

We further assume that, owing to the presence of a form factor arising from strong interactions, the integration over the pion momentum may be cut off at M (where M is of the order of the nucleon mass m). In view of the presence in the diagram of a quadratic divergence in the integration over the lepton momenta, it is obvious that the matrix element $\mathfrak{M}$ for the transition $K^0 \to \bar{K}^0$ will be of the order $\mathfrak{M} \sim G^2\Lambda^2M^3$, i.e., for $\Lambda \sim G^{-1/2}$ we have $\mathfrak{M} \sim GM^3$. On the other hand this matrix element is proportional to the difference Δm_K in the masses of the K_1^0 and K_2^0 mesons, which is known [3] to be $\Delta m_K \sim 1/\tau(K_1^0)$ [where $\tau(K_1^0) \approx 10^{-10}$ sec is the lifetime of the K_1^0 meson], i.e., of the order of G^2m^5. Consequently the existence of the decay processes $K^0 \to \pi^- + e^+ + \nu$ and $K^0 \to \pi^+ + e^- + \bar{\nu}$ leads to the conclusion that the cutoff Λ, up to which the theory of weak interactions of leptons is applicable, is comparatively small.

For a more concrete estimate we calculate the matrix element $\mathfrak{M}$ assuming the interaction Hamiltonian for the decay $K^0 \to \pi^- + e^+ + \nu$ to be of the form*

$$H = \frac{1}{\sqrt{2}} G\beta q_\mu (\bar{\psi}_\nu \gamma_\mu (1 + \gamma_5) \psi_e) \varphi_{K^0} \varphi^{+}_{\pi^-} + \text{H.c.} \quad (1)$$

where q_μ is the momentum of the K^0 meson and β is a real constant, $\beta^2 \approx 0.1$. Assuming for simplicity a form factor which depends on the pion momentum only we obtain for the matrix element $\mathfrak{M}$ (including also the contributions due to $K^0 \to \pi + \mu + \nu \to \bar{K}^0$)

$$\mathfrak{M} = \frac{1}{2} \frac{1}{(2\pi)^3} G^2\beta^2\Lambda^2 m_K \quad (2)$$

(where m_K is the mass of the K meson). With the normalization chosen the matrix element $\mathfrak{M}$ equals the difference in the masses of the K_1^0 and K_2^0 mesons due to the diagram in question: $\Delta m_K = \mathfrak{M}$. Introducing for Δm_K the experimental value we obtain the following estimate

$$\Lambda \sim 0{,}5 m^2/M, \quad (3)$$

i.e., Λ turns out to be of the order of a nucleon mass.

We are thus led to the following conclusions: if the K^0 meson decays both according to the mode $K^0 \to \pi^- + e^+ + \nu$ and the mode $K^0 \to \pi^+ + e^- + \bar{\nu}$, then it follows from the magnitude of the experimentally observed mass difference of the K_1^0 and K_2^0 mesons that 1) either the leptonic weak interactions are cut off at energies of the order of a nucleon mass (for example, the weak interaction is mediated by a vector meson, whose mass is of the order of the nucleon mass†), 2) or the integral (close loop) over the leptons in the diagram is not quadratically divergent. In the latter case the leading divergence (of the order of $G^n\Lambda^{2n+2}$) should be absent not only from the diagram here considered, but from any diagram of this type in which the lepton loop can be made arbitrarily more complicated as a consequence of leptonic interactions. The existence of such a requirement (whose possibility has been indicated previously [2]) imposes definite limitations on the structure of the weak lepton-lepton interaction. A more detailed discussion of this question will be presented in a separate paper.

The author is greateful to L. B. Okun' for useful discussions.

*In the expression for the Hamiltonian we take into account only terms proportional to q_μ, the momentum of the K meson. The inclusion of terms proportional to the momentum of the pion does not affect our conclusions.

†In that case, in order to forbid the process $\mu \to e + \gamma$, it is necessary to have the muon and electron neutrinos not identical.

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THE ππ INTERACTION IN π⁻p COLLISIONS AT 7.2 BeV

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Submitted to JETP editor March 5, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 1413-1415 (May, 1962)

In an investigation of multiple pion production in π^-p collisions at 7.2 BeV in a liquid hydrogen chamber in a magnetic field, we selected 675 double-pronged stars. An analysis of these events permitted us to isolate 196 elastic scattering events. [1] Among the 479 inelastic interaction events which remain, 142 cases were selected in which the positively charged particle is a proton. Events were selected when the proton range exceeds 0.4 cm, and if the proton did not remain inside the chamber, then events with proton momentum smaller than 1.5 BeV/c were selected. The protons were identified by their range and ionization (for slow protons) or by momentum and ionization.

The measurement of momenta and angles-of-flight of the protons allows us to plot the distribution (of events) with respect to the square of the total energy of the π mesons in their center-of-mass system for the reaction under consideration

$$\pi^- + p \to p + \pi^- + k\pi^0. \tag{1}$$

The resulting distribution with respect to ω^2 (being in fact the distribution with respect to the effective masses of the system of outgoing π mesons) is shown in Fig. 1.

The same graph shows (in addition to the experimental histogram) the phase-volume curve normalized to the total number of events. Comparison of the resulting histogram and the phase-volume curve shows that a large number of events, clustered in a narrow maximum, are observed in the region $\omega^2 \sim 30$. The most probable explanation for the appearance of this maximum is the hypothesis that the reaction

$$\pi^- + p \to p + \rho^- \to p + \pi^- + \pi^0 \tag{2}$$

takes place in a considerable number of events, where ρ^- is the ρ meson with mass ~ 750 BeV, [2] which has been previously observed in many investigations.