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О возможном нарушении CP-инвариантности в распадах очарованных частиц

В работе рассматривается возможное нарушение CP-инвариантности в распадах "очарованных" частиц. Предполагается изучать распады D^0-, $\tilde{D}^0$-мезонов, образующихся при рождении резонанса в e^+e^--столкновениях.

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Okun L.B., Pontecorvo B.M., Zakharov V.I. **E2 - 8530**

On the Possible Violation of CP-Invariance in the Decays of Charmed Particles

The possibility is considered that CP-invariance is violated in charmed particle decays. The study of the $D^0 - \tilde{D}^0$ system, which would be produced in e^+e^- collisions, is suggested for the investigation of CP violating effects.

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The recently discovered[1-4] narrow resonances with masses of 3.1 and 3.7 GeV are widely believed to possess hidden charm. If this is true many charmed particles will certainly be found in the nearest future and, among the others, D^0 and $\tilde{D}^0$ - mesons with the quark content $p'\tilde{p}$ and $\tilde{p}'p$, respectively, where p' is the charmed quark. There is a close analogy between the properties of $D^0 - \tilde{D}^0$ system and those of the well-known $K^0 - \tilde{K}^0$ system. It is natural to expect possible CP-invariance violations in the decays of D^0 mesons, and in this Letter we wish to discuss how such effects could be searched for experimentally.

Let us consider the production of a resonance in e^+e^- collisions which decays into a D^0 and $\tilde{D}^0$ pair (such resonances must exist according to the quark model and have masses larger or of the order of 4-5 GeV). Let D^0-mesons decay into charge conjugated states, say, $D^0 \to K^- \mu^+ \nu_\mu$ and $\tilde{D}^0 \to K^+ \mu^- \tilde{\nu}_\mu$ (we assume hereafter the validity of the $\Delta C = \Delta S$ selection rule, which for such decays follows from the quark model, C and S being the charm and strangeness).

If there were no vacuum transitions $D^0 \leftrightarrow \tilde{D}^0$, all the pairs $D^0 \tilde{D}^0$ would decay into $(K^- \mu^+ \nu_\mu)(K^+ \mu^- \tilde{\nu}_\mu)$. However, due to the $D_0 \leftrightarrow \tilde{D}_0$ transitions and the formation of the D_L and D_S states*, there will appear a number of decays

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*Here D_L and D_S are defined in the same way as K_L and K_S (see, eq. (3)). It is worth noting, however, that the D_L and D_S lifetimes are both very short. Just this circumstance makes the observation of CP-violation effects so difficult.

into $(K^+\mu^-\tilde{\nu}_\mu)(K^+\mu^-\tilde{\nu}_\mu)$ and $(K^-\mu^+\nu_\mu)(K^-\mu^+\nu_\mu)$ pairs. Let us denote the number of such rare pairs as N^{++} and N^{--}. One readily finds that the ratio of $N^{++}+N^{--}$ to the number $N^{+-}+N^{-+}$ of "normal" pairs $(K^+\mu^-\tilde{\nu}_\mu)(K^-\mu^+\nu_\mu)$ + $(K^-\mu^+\nu_\mu)(K^+\mu^-\tilde{\nu}_\mu)$ is given by

$$R = \frac{N^{++}+N^{--}}{N^{+-}+N^{-+}+N^{++}+N^{--}} = \frac{1}{2}\left\{\frac{(\Gamma_S-\Gamma_L)^2+4(\Delta m_{SL})^2}{(\Gamma_S+\Gamma_L)^2+4(\Delta m_{SL})^2}\right\}, \qquad (1)$$

where Γ_S and Γ_L are the widths of the D_S - and D_L mesons, Δm_{SL} is their mass difference.

According to the estimates of ref.[5] $\Gamma_S \approx \Gamma_L \sim 10^{11} - 10^{12}$ sec^{-1}, $(\Gamma_S-\Gamma_L)/(\Gamma_S+\Gamma_L) \sim tg^2\theta \simeq 5\times10^{-2}$, where θ is the Cabibbo angle. If $|\Delta m_{SL}| \ll \Gamma_S - \Gamma_L$, then $R \sim tg^4\theta \sim 10^{-3}$. If, however, $|\Delta m_{SL}| > \Gamma_S - \Gamma_L$, then the expected value of R is larger. For example, the existence of first order transitions with $\Delta C = 2$ would lead to $|\Delta m_{SL}| \gg \Gamma$ and $R = 1/2$.

CP-violation would give a charge asymmetry

$$\delta_D \equiv \frac{N^{++}-N^{--}}{N^{++}+N^{--}} = \frac{4\mathrm{Re}\,\epsilon_D\,(1+|\epsilon_D|^2)}{(1+|\epsilon_D|^2)^2+4(\mathrm{Re}\,\epsilon_D)^2} \simeq 4\mathrm{Re}\,\epsilon_D, \qquad (2)$$

where ϵ_D is the CP-violation parameter in the wave functions of D_S and D_L mesons*:

$$D_S \sim D^0(1+\epsilon_D) + \tilde{D}^0(1-\epsilon_D) \sim D_1 + \epsilon_D D_2$$

$$D_L \sim D^0(1+\epsilon_D) - \tilde{D}^0(1-\epsilon_D) \sim D_2 + \epsilon_D D_1, \qquad (3)$$

where D_1 and D_2 are the pure CP states.

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* Let us note that eq. (1) is in fact valid in the limit of $\epsilon_D = 0$. Taking into account the CP-violation we obtain:

$$R^{-1} = 1 + \frac{2|1-\epsilon_D^2|^2}{|1-\epsilon_D|^4+|1+\epsilon_D|^4}\;\frac{(\Gamma_S+\Gamma_L)^2+4\Gamma_S\Gamma_L+4(\Delta m_{SL})^2}{(\Gamma_S+\Gamma_L)^2-4\Gamma_S\Gamma_L+4(\Delta m_{SL})^2}.$$

Let us note that, generally speaking, ϵ_D increases with decreasing Δm_{SL}. Hence, the possibility that $\epsilon_D \gg \epsilon_K \sim 2\times10^{-3}$ cannot be ruled out, (here ϵ_K is the CP-violation parameter in neutral kaons). In this case $\delta_D \gg 1\%$ and a statistics of $N^{++} \approx 10^4$ decays, would be necessary in order to search for CP-violation. For luminosities of e^+e^- colliding beams close to 10^{33} cm^2 sec^{-1} such an experiment is feasible.

The charge asymmetry could be looked for not only in the $K\mu\nu_\mu$ modes but also in other decay channels such as $Ke\nu_e$, $K\mu\nu_\mu\pi^+\pi^-$ and so on*. Let us note also that an intermediate resonance is not necessary for observing CP-violation; the annihilation $e^+e^- \to \gamma \to D^0\bar{D}^0$ could be used as well as far as it is proceeding via one virtual photon. If the charge asymmetry turns out to be small, then special considerations should be given to the background contribution of the two photon intermediate state, which could also give charge asymmetry.

As a matter of fact, we have discussed so far the superweak model of CP-violation. There might exist, however, a milliweak or even a millistrong CP-violation in the decays of charmed particles. In this respect it would be interesting to search for a difference in π^+ and π^- spectra in, say, $\pi^+\pi^-\pi^0$ decays of ψ^0 or D^0-mesons. The search for C-odd decays such as $\psi^0 \to \eta\pi^0$, $\psi^0 \to X^0\eta$ is also justified. The effect could be large if the C-odd millistrong $p'\bar{p}'$-annihilation into usual hadrons is not suppressed.

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* The investigation of the charge asymmetry in the $K\pi$ channels, on one hand, would be facilitated by the expected relatively large width of the decays $D^0 \to K^-\pi^+$ and $\bar{D}^0 \to K^+\pi^-$, but, on the other hand, is made difficult by the fact that with a probability $\sim \sin^4\theta$ there must be present the decays $D^0 \to K^+\pi^-$ and $\bar{D}^0 \to K^-\pi^+$. This increases the number of "rare" pairs $(K^+\pi^-)(K^+\pi^-)$ and $(K^-\pi^+)(K^-\pi^+)$ by an equal amount and consequently "dilutes" the CP violating charge asymmetry effects searched for.

The observation of the effects discussed above could give a clue to the understanding of the whole problem of CP-violation.

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