CP nonconservation in rare decays of B_s^0 mesons

Ya. I. Azimov, N. G. Ural'tsev, and V. A. Khoze
B. P. Konstantinov Institute of Nuclear Physics, Academy of Sciences of the USSR

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CP-odd effects might be sought in "forbidden" decays of B_s^0 mesons involving a $b \to u$ transition. In the decay of B_s^0 or $\overline{B}_s^0$ to the same final state $[\rho^0(\omega)K_s, \pi^0(\eta)K_s$, etc.$]$, CP-odd effects should be of order unity in the standard model. The CP nonconservation would be observed most conveniently as a spatial oscillation of the yield in "tracer" beams of B_s^0 mesons. The integrated charge asymmetry of the yield $(l^{\pm} + \rho^0 K_s)$ in e^+e^- annihilation is expected to be significant with a relatively light t-quark $(x_{B_s} \lesssim 1)$.

CP nonconservation is acknowledged to be one of the most intriguing problems in the physics of elementary particles. So far, however, its effects have been limited to the decays of K^0 mesons, so that a theoretical interpretation of the phenomenon has been hindered. There is accordingly considerable interest in neutral B^0 mesons, where analogous effects are expected.

Unfortunately, the prospects for observing CP nonconservation in B mesons by the methods which have been discussed appear poor. For B_d^0 mesons, for example, the mixing itself is slight (in the standard model, we would have $x = \Delta m/\Gamma \lesssim 0.1$ with $m_t \sim 40$ GeV). Since Re$\bar{\epsilon}$ unavoidably contains a suppression factor at least $\sim m_b^2/m_t^2$, there is no hope for observing a CP-odd charge asymmetry in, say, the yield of dileptons. For B_s^0 mesons, the mixing is expected to be pronounced ($x_{B_s} \sim 1.3$ with $m_t \sim 40$ GeV), but Re$\bar{\epsilon}_{B_s}$ contains an additional suppression $\sim \sin^2\theta_c \simeq 0.05$.

There have also been suggestions of an experimental search for other CP odd asymmetries, specifically those of "milliweak" origin, which do not require a CP violation directly in the mixing[1] B^0–$\overline{B}^0$. For example, the effective difference between the $B^0 \to f$ and $\overline{B} \to f$ yields, where f is the same state, with a definite CP parity, may be a consequence of an interference between $B^0 \to f$ and $B^0 \to \overline{B}^0 \to f$ channels. A mixing is necessary here, but CP nonconservation is not required in the transitions $B^0 \rightleftharpoons \overline{B}^0$.

An asymmetry (in terms of the sign of the lepton) thus appears in the $(l^{\pm} f)$ yield in e^+e^- annihilation (for B_d, convenient decays are those to $J/\psi K_s$, $D\overline{D}K_s$, etc.). The magnitude of this asymmetry depends strongly on the initial state of the $B_d\overline{B}_d$ pair. For a C-odd state, there will be essentially no effect, while for a C-even state we would have

$$A = \frac{\sigma(l^+f) - \sigma(l^-f)}{\sigma(l^+f) + \sigma(l^-f)} \simeq \eta \frac{2x}{(1+x^2)^2} \sin 2\Phi_{B_d} \qquad (1)$$

$(\eta = \pm 1$ is the CP parity of the state f). In the standard model we would have $\Phi_{B_d} \sim 1$, and A could be $\sim 10\%$.

In B_s mesons we would expect $x_{B_s} \gtrsim 1$. The most convenient decays for a study of the milliweak CP violation would be decays of the type $B_s \to F^+ F^-$. Here again, however, as in the mixing, the effects of the CP nonconservation would be small: $\sin 2\Phi_{B_s} \lesssim 0.03$. The reason for these small effets is easy to see.[2] The B_s ($\overline{B}_s$) mesons consist of b and s quarks, so that the transitions $B_s \rightleftharpoons \overline{B}_s$, like the decays of B_s mesons, would not require going beyond the second and third generations. In other words, we are essentially dealing here with a four-quark case, in which there is no observable CP violation, as we know. In order to obtain CP-odd effects, it would be necessary to "sense" the first generation of quarks, i.e., to deliberately "jump over" to the first generation (and, of course, jump back). We would thereby obtain an additional small factor $\sim \sin^2\theta_c$ for CP-odd effects in B_s mesons. Clearly, with a greater number of generations, $\mathrm{Re}\bar{\epsilon}_{B_s}$ and Φ_{B_s} might not turn out to be so small,[3] while in super-Kobayashi-Maskawa models we would *naturally* expect to find these suppression factors.

These arguments show that the situation should change for the "forbidden" decays of B_s involving an $l \to u$ transition, e.g., $B_s^0 \to \rho^0 K_s$ and $\pi^+ K^{*-} \to \pi^+ \pi^- K_s$. Here the corresponding phase $\widetilde{\Phi}_{B_s}$ is not small:

$$\Phi_{B_s} \simeq \alpha \sim 1, \tag{2}$$

where α is the CP-violating phase of the quark mixing matrix in the Maiani parametrization.[3] We wish to emphasize that, in contrast with all the CP-odd effects that have been proposed previously, which depend only weakly on α in the region of "maximum CP violation," $\alpha \sim \pi/2$, this asymmetry changes most sharply specifically at $\alpha \sim \pi/2$.

An obvious disadvantage of the reactions proposed here is their low relative probability, which stems primarily from the strong suppression of $b \to u$ transitions in comparison with the $b \to c$ channel. In addition, the relative number of specific exclusive decays of $\rho^0 K_s$, ωK_s, $\pi^0(\eta)K_s$, etc., is small, although there is the possibility, in principle, of a summation of events with an explicity determined CP-parity of the final state. The limitation usually cited on the width of the (semileptonic) decay $b \to u$ with respect to the decay $b \to c$, i.e., $R < 3\%$, may be much too low, and the relative number of $b \to u$ decays might reach[4] 8%. Decays of the type $B_s \to \omega K_s$, $\pi^0(\eta)K_s$ would themselves undoubtedly be convenient for identification. At the same time, the large asymmetry would substantially relax the requirements on the total statistical base.

In e^+e^- annihilation, a CP-odd effect of this sort would be particularly convenient at $x_{B_s} \lesssim 1$ [see (1)], which would be possible with a relatively light t-quark ($m_t \lesssim 40$ GeV). A $B_s \overline{B}_s$ pair might be formed in a CP-even state, e.g., from $B_s^* \overline{B}_s$ produced in a suitable resonance. It might also be possible to study an asymmetry of the type in (1) far beyond the $B\overline{B}$ production threshold.

Another possibility for measuring the milliweak asymmetry $B^0(\overline{B}^0) \to f$ would be to observe a spatial oscillation of the yield of the final state f in tracer B_s^0 beams[2] (this method would be particularly convenient at large $x_{B_s} \gtrsim 1.5$). Here the relative amplitude of the oscillatory component of the f yield would be $\sin 2\widetilde{\Phi}_{B_s}$; i.e., the CP-odd effect might be of order unity. Tracers beams of B_s mesons could be produced in the fragmentation region in the scattering of high-energy hyperon or kaon beams in a target (A. A. Vorob'ev and the present authors have discussed this formulation of the experiment).

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