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Spontaneous CP violation and neutral B meson decays

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Abstract. A model in which CP is spontaneously broken is described; it solves the strong CP problem and provides an additional mechanism for weak CP violation. This is the aspon model. Application to B decays leads to predictions for CP asymmetries much smaller than expected from the KM mechanism of explicit CP breaking.

In this presentation I shall cover the three topics all of which pertain to the aspon model:

1)The motivation, arising from the strong CP problem.

2)The phenomenology of CP violation, giving upper bounds on the masses.

3)Estimation of CP asymmetries in B meson decays.

Topic (3), done in collaboration with Ackley, Kayser and Leung, is the most recent work in the model so I shall emphasize it.

(1) Solution of Strong CP Problem.

In solving the strong CP problem there are three alternatives:

1) Axion

2) $m_u = 0$

3) Spontaneous (or soft) CP violation

(1) is looking less and less plausible experimentally since the allowed window is $10^{-5}eV \leq m_a \leq 10^{-3}eV$.

(2) is at odds with pseudoscalar meson masses and spontaneous chiral symmetry breaking.

The *aspon model* is an economical (minimal) version of (3).

The strong CP problem is due to the term $\Theta_{QCD}G_{\mu\nu}\tilde{G^{\mu\nu}}$ in the QCD lagrangian. The physical quantity $\bar{\Theta} = (\Theta_{QCD}+\Theta_{QFD}) \leq 2\times 10^{-10}$ for $d_n \leq 10^{-25}e.cm.$ where $\Theta_{QFD} = -argdetM$, M being the quark mass matrix.

With a CP invariant lagrangian $\Theta_{QCD} = 0$ so we must arrange that $\Theta_{QFD} \leq 2 \times 10^{-10}$.

To do this we introduce $U(1)_{new}$ which will be local (gauged). Thus the model has gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{new}$. All the particles in the three family standard model are neutral under this $U(1)_{new}$. In the simplest version of the aspon model we add one doublet of vector-like quarks which carry the new charge $Q_{new} = 1$. There are also two complex scalars χ_α with $\alpha = 1,2$ and $Q_{new} = 1$. The reason for having at least two is so that the phase of the VEVs cannot be removed by a gauge transformation - assuming there is a nonzero relative phase between them.

The new quarks have gauge-invariant (heavy) Dirac masses and Yukawa couplings to the light quarks:

$$h_i^\alpha U_L^C u_L^i \chi_{alpha}; \qquad h_i^\alpha D_L^C d_L^i \chi_{alpha}. \tag{1}$$

Here $\alpha = 1,2$ and i = 1,2,3. The superscript C implies charge conjugate. There are *no* Yukawa couplings to U_L or to D_L because of the $U(1)_{new}$ gauge invariance.

The gauge invariance under $U(1)_{new}$ forces the 4×4 quark mass matrices (both *up* and *down* sectors) to have a texture such that the determinant is real. The diagonal blocks are real because of CP conservation; let the heavy quarks have mass M. The off-diagonal terms are of the form:

$$F_i = \sum_\alpha h_i^\alpha < \chi_\alpha > \tag{2}$$

and arise from the off-diagonal Yukawa couplings listed earlier. Only one of the two off-diagonal blocks has this form, the other being zero; this is how the determinant is real.

(2) The Phenomenology of CP Violation, Giving Upper Bounds on the Masses

The Yukawa couplings h_α^i are restricted to be << 1 by the limit on $\bar{\Theta}$ which is generated by one-loop corrections. In diagonalization of the quark mass matrix the relevant expansion parameter is $x_i = F_i/M$ ($i = 1,2,3$ for the three families). In the aspon model these satisfy $x_i << 1$.

Since $U(1)_{new}$ is clearly anomaly free, it can be gauged and its gauge boson, the *aspon* become massive by the Higgs mechanism. Combining the upper limit on $\bar{\Theta}$ and the values of ϵ and ϵ' from K^0 decay it is possible to show that both the aspon and the vector-like quarks have masses $\leq 600 GeV$. The analysis also bounds the values of $|x_i|$ to be $\leq 10^{-2}, 10^{-3}, 10^{-4}$ for i = 1,2,3 respectively.

I shall not go through the details here. In the treatment of CP violation, there is a parallel to the recent paper of Deshpande and He (OITS-529 12/93) which uses a $S_3 \times Z_3$ family symmetry introdued in 1991 by Ernest Ma. Their case (a) has hard explicit CP violation, but their case (b) has spontaneous violation and has too small a KM phase to account for the effect in the K system which is instead explained by charged Higgs exchange [the analog of aspon exchange].

In the MSSM new CP phases occur and must be suppressed to avoid too large a value of d_n. Babu and Barr (1993) suggest spontaneous CP violation at a high scale to solve this by providing phases only in gaugino mass terms.

These are two examples of other recent work suggesting spontaneous CP violation. They both differ from the aspon model as can be seen by the fact that they both require an axion to solve strong CP.

(3) Estimation of CP Asymmetries in B Decays

In B decays, using the KM mechanism it has been estimated that with 10^8 samples one could see CP asymmetries and begin to check the unitarity relations required for the (complex) CKM matrix elements.

As shown in [1], the details are different in the aspon model because aspon exchange can compete with the usual box diagrams for the decay amplitudes. In the K system, the mixing is dominated by aspon exchange and that led to the upper limits on the masses mentioned above. The large phase there compensated for the small phase in the $K \rightarrow \pi\pi$ amplitude from W exchange.

For the B system, the mixing acquires a sizeable contribution from the W^+W^- box graph and the compensation is incomplete for the small phase occurring in the decay amplitude. The reason that the aspon exchange is relatively less important in the mixing can be traced to two large suppression factors: (1) $(m_c/m_t)^2 \simeq 10^{-4}$ and (2) $|x_3/x_2|^2 \simeq 10^{-2}$.

As a result, in a sample of 10^8 B decays one would *not* see the CP asymmetry if the aspon model were correct. This is good in that it will refute the standard model if one defines the KM mechanism as a part thereof (this may be unfair to the standard model). It is bad because there would still be no example of CP violation seen outside of the neutral K system.

To confirm the aspon model, the most convincing would be the production of the aspon particle in a collider.

In conclusion, if CP asymmetries are undetectably tiny in B decay, spontaneous CP violation is an alternative to the KM mechanism.

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References

[1] A. W. Ackley, P. H. Frampton, B. Kayser and C. N. Leung, Phys. Rev. D (1994, in press) and references cited therein.