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CP INVARIANCE AND THE SHADOW UNIVERSE*

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It has been reported by two experimental groups[1,2] that the long-lived component of the neutral K-meson beam exhibits the two-pion decay mode. The decay width for this mode relative to the normal $K_1 \to 2\pi$ width is given approximately by 5×10^{-6}. If this decay should represent $K_2 \to 2\pi$, it should be a clear indication against CP invariance. Some people[3-5] accept this as evidence against CP invariance, while others try to incorporate this result with CP invariance.[6-10] In this article a new interpretation of this process is proposed based on the assumption of CP invariance.

In order to give an interpretation of this phenomenon based on CP invariance it seems indispensable to attribute this mode of decay to forces exerted by the environment which under normal circumstances would escape from our observation. This force must be very weak and its range must be of macroscopic or even cosmological dimension, and furthermore it should act on the K and $\bar{K}$ mesons with opposite signs. Thus several people have introduced a vector field coupled to the hypercharge.[6-8] Unlike electrodynamics, however, there seem to be difficulties in choosing the mass of the quantum of this field exactly equal to zero because of the lack of rigorous gauge invariance, which prevents us from eliminating infrared divergences.[11]

Recently Lipkin and Abashian[10] proposed another possible scheme by attributing the two-pion decay mode to a new kind of K meson, K_1'. In this scheme what decays into two pions is not the K_2 meson but the K_1' meson which is even under CP. They have shown that a sufficiently long lifetime of K_1' can account for the observed results. There are two unnatural assumptions involved in their scheme: first, accidentally degenerate K_1 and K_1' mesons, and second, the production of the K_1' mesons by strong interactions, in spite of the fact that they have never been seen in the past.

In this paper we shall present a theory which is free from these objections. First, in the vector-meson model the effects of geometrically far objects such as galaxies are taken into account, but the objects exerting such forces need not be geometrically far. The only necessary constraint is that the forces must be extremely weak in order not to be recognized in other processes. Second, in the K_1'-meson model, they need not be produced by strong interactions. We thus propose a new interpretation based on the following assumptions:

(I) The universe that consists of all the particles known to us will be called U_a. Let us assume the existence of another universe U_b embedded into the same space-time framework as U_a. U_a is our universe, and U_b will be called the shadow universe.

(II) When weak interactions are discarded, U_a and U_b are completely identical, and there are no interactions between them. Then the total Hamiltonian H consists of two parts H_a and H_b describing the universes U_a and U_b, respectively, i.e.,

$$H = H_a + H_b, \tag{1}$$

and this Hamiltonian is invariant under a transformation called "universe conjugation":

$$\begin{aligned} p_a &\rightleftarrows p_b, \\ n_a &\rightleftarrows n_b, \\ \pi_a &\rightleftarrows \pi_b, \\ \gamma_a &\rightleftarrows \gamma_b, \text{ etc.,} \end{aligned} \tag{2}$$

where p_a denotes the proton in the universe U_a, p_b the proton in the universe U_b, and so on. Two kinds of photons γ_a and γ_b are introduced in order to forbid electromagnetic interactions between the two universes.

(III) Since the two universes are embedded into a common space-time framework, we shall assume that a common gravitational field is shared between them.

(IV) Weak interactions consist of three parts,

$$H_w = H_{wa} + H_{wb} + H_{wab}, \tag{3}$$

where H_{wa}, H_{wb}, and H_{wab} are the weak interactions in U_a, in U_b, and between U_a and U_b, respectively. For reasons to be made clear later, we further assume

$$H_{wa} \gg H_{wb}. \tag{4}$$

(V) Rigorous conservation laws are valid separately in both universes, except for those related to the proper Lorentz group, such as the conservation of energy-momentum and of angular momentum.

In what follows we shall list the consequences of these assumptions.

(1) First of all, the particles of the shadow universe cannot be detected by our instruments since they do not interact with our electromagnetic field.

(2) The masses of the K_1 meson in our universe and of the K_1' meson in the shadow universe are degenerate as a consequence of the invariance of the strong interactions under universe conjugation. This gives an explanation for the degeneracy of the K_1 and K_1' masses assumed ad hoc in the Lipkin-Abashian scheme. Furthermore, the K_1' mesons cannot be produced by strong interactions in our universe.

(3) It is still possible for the K_1' meson to affect K_1 decay. When CP invariance is assumed, the K_1 and K_2 channels are not coupled; but K_1 and K_1' are coupled, in a similar manner as K and $\bar{K}$ are through H_{wab}, and the state vector $\psi(t)$ of the K_1-K_1' system expressed by

$$\psi(t) = c(t)\,|K_1\rangle + c'(t)\,|K_1'\rangle \tag{5}$$

should obey a Schrödinger equation of the form

$$i\hbar\partial\psi(t)/\partial t = M\psi(t), \tag{6}$$

where M is the mass matrix given by

$$M = \begin{pmatrix} \mathfrak{M}_a & g \\ g & \mathfrak{M}_b \end{pmatrix}. \tag{7}$$

$\mathfrak{M}_a$ and $\mathfrak{M}_b$ are the complex self-energies of the K_1 and K_1' due to the weak interactions H_{wa} and H_{wb}, respectively, and g denotes the amplitude for

$$K_1 \rightleftarrows K_1', \tag{8}$$

which does not violate any strict conservation laws. This is not the case, however, for other unstable particles such as the Λ^0 or neutron, since the virtual transitions corresponding to (8) are forbidden by conservation of baryon number which holds in both universes separately. From Eq. (4), we conclude that

$$|\mathfrak{M}_a| \gg |\mathfrak{M}_b|, \tag{9}$$

and in what follows we shall neglect $\mathfrak{M}_b$. To be consistent with Eq. (4), we assume that the rate for $K_1 \to 2\pi$ is much larger than that for $K_1' \to 2\pi'$. Then, due to the coupling (8), K_1' can decay into 2π and K_1 into $2\pi'$. The latter would escape our observation and contradicts our experience. Equation (4), however, leads us to the conclusion that the branching ratio $K_1 \to 2\pi'$ to $K_1 \to 2\pi$ should be very small, i.e.,

$$\frac{w(K_1 \to 2\pi')}{w(K_1 \to 2\pi)} \ll 1. \tag{10}$$

This is the reason why we assumed Eq. (4). The above situation is most clearly illustrated by an extreme case $H_{wb} = 0$, in which both K_1 and K_1' decay exclusively into our pions.

Anyway, the presence of the K_1' meson generates two distinctive lifetimes for the process $K \to 2\pi$, and the time dependence of the decay curve is given by a formula more or less similar to the Treiman-Sachs formula.[12] The shorter lifetime can practically be identified with the normal K_1 lifetime, but the longer one is new and is determined solely by the matrix M. We can propose an experimental method at this stage to distinguish between our scheme and the CP-violating decay $K_2 \to 2\pi$. For a sufficiently long period of time as compared with the K_1 lifetime, the neutral K-meson beam will consist mainly of the long-lived component in both cases, and it is possible to measure the longer lifetime by plotting the two-pion decay rate as a function of time. If the measured longer lifetime coincides with that of the known K_2 lifetime, it is an indication for $K_2 \to 2\pi$. If, however, it turns out to be different from the K_2 lifetime, say between the K_1 and K_2 lifetimes, it is an indication in favor of our scheme.

(4) One might think that the present scheme

leads to the process

$$K_1' \to 2\pi, \qquad (11)$$

which should be interpreted as a spontaneous pion-pair production out of nothing.[13] The chances for seeing (11) depend on the matter density in the shadow universe, and the matter density in the shadow universe in our neighborhood is supposed to be very low. If the matter density in the shadow universe were high, the gravitational force exerted by its stars would disturb the motion of the solar system, although they cannot be seen by us. In principle, it should be possible to predict their existence, as was the case for Neptune and Pluto. This does not seem to be the case, however, indicating a low density of the shadow stars in the neighborhood of our solar system. It could be, however, that the shadow universe has been the energy source of our universe in the past, as illustrated by Reaction (11).

To conclude, we would like to emphasize the importance of the measurement of the exponential decay curve for the long-lived component of the neutral K-meson beam for the two-pion mode of decay in order to check whether it really is the K_2 meson or not that decays into two pions.

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$$R(t) \approx |\beta|^2 \Gamma_L \exp(-\Gamma_L t),$$

where Γ_L is the decay width of the long-lived component of the K_1 meson beam. We can determine both $|\beta|$ and Γ_L from the two experiments quoted above, i.e., introducing $r(t) = R(t)/R_2(t)$, where $R_2(t) = \Gamma_2 \exp(-\Gamma_2 t)$, we find

$$r(0.07\tau_2) = 0.06, \quad r(0.55\tau_2) = 0.002,$$

and we get

$$\Gamma_L \approx 8\Gamma_2, \quad |\beta| \approx 0.1.$$

Also considering that Γ_L is the negative of twice the imaginary part of one of the eigenvalues of the mass matrix (7), we get

$$|\mathfrak{M}_a| \lesssim 0.7\Gamma_1.$$

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