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ABSOLUTE DISTINCTION BETWEEN PARTICLES AND ANTIPARTICLES

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RESUMEN

Se reexamina la distinción absoluta entre partículas y antipartículas usando la interferencia entre K_S^0 *y* K_L^0 *a través de dos piones. No se supone que el experimento comienza con* K^0 *o* $\overline{K}^0$*, sino que se define a la materia y a la antimateria operacionalmente. Esto permite la comparación del experimento de interferencia realizado en la Tierra y en algún mundo distante. Se pueden encontrar, entonces, diferencias en el comportamiento del término de interferencia en un mundo compuesto de materia y otro de antimateria.*

ABSTRACT

The absolute distinction between particles and antiparticles by the inter-

ference of K_S^0 and K_L^0 into two pions is re-examined. We do not assume the experiment begins with K^0 or $\bar{K}^0$. Instead we define matter and anti-matter operationally. This permits a comparison of the interference experiment performed terrestrially and on some distant world. A distinction can now be made from the behaviour of the interference term between a world composed of matter and one of anti-matter.

I. INTRODUCTION

It has been observed that the interference experiments of K_S^0 and K_L^0 into $\pi^+\pi^-$ [1-5] permit an absolute distinction between particles and anti-particles.[6] The published argument follows. Define K_S^0 and K_L^0 as symmetric and anti-symmetric combinations of K^0 and $\bar{K}^0$:

$$K_S^0 = \frac{K^0 + \bar{K}^0}{\sqrt{2}}$$

and

$$K_L^0 = \frac{K^0 - \bar{K}^0}{\sqrt{2}} \tag{1}$$

The $|K^0(\tau)>$ state as a function of time is:

$$|K^0(\tau)> = \frac{1}{\sqrt{2}}\,|K_S^0>\,e^{-i(m_S - i\Gamma_S/2)\tau} + \frac{1}{\sqrt{2}}\,|K_L^0>\,e^{-i(m_L - i\Gamma_L/2)\tau} \tag{2}$$

The amplitude for the $K^0 \to \pi^+\pi^-$ decay is given by,

$$<\pi^+\pi^-|K^0(\tau)> = \frac{\langle\pi^+\pi^-|K_S^0\rangle}{\sqrt{2}}\left\{e^{-i(m_S - i\Gamma_S/2)\tau} + \eta_{+-}\,e^{-i(m_L - i\Gamma_L/2)\tau}\right\}. \tag{3}$$

with

$$\eta_{+-} = |\eta_{+-}| e^{i\phi_{+-}} = \frac{\langle \pi^+\pi^- | K_L^0 \rangle}{\langle \pi^+\pi^- | K_S^0 \rangle}$$

and the $\pi^+\pi^-$ intensity is given from Eq. (3) by

$$I(\tau) = I_0 \left\{ e^{-\Gamma_S \tau} + |\eta_{+-}|^2 e^{-\Gamma_L \tau} + \right.$$

$$\left. + 2 |\eta_{+-}| e^{-(\Gamma_S + \Gamma_L)\tau/2} \cos\left[(m_S - m_L)\tau + \phi_{+-} \right] \right\} . \tag{4}$$

The intensity for $\bar{K}^0 \to \pi^+\pi^-$ is simply obtained by reversing the sign of the interference term in equation (4). Note that, if

$$K_S^{0\prime} = \frac{\bar{K}^0 + K^0}{\sqrt{2}}$$

and (5)

$$K_L^{0\prime} = \frac{\bar{K}^0 - K^0}{\sqrt{2}}$$

then

$$\eta'_{+-} = |\eta'_{+-}| e^{i\phi'_{+-}} = \frac{\langle \pi^+\pi^- | K_L^{0\prime} \rangle}{\langle \pi^+\pi^- | K_S^{0\prime} \rangle} = -\eta_{+-}$$

and the same signs are obtained as previously. Therefore an absolute distinction between K^0 and $\bar{K}^0$ is possible from the sign of the interference term.

We agree with this conclusion. We disagree with the argument. The above description of the interference experiment assumes that we can always specify, before the experiment is performed, which particles ar: K^0 and which are $\bar{K}^0$.

However, this is precisely the information we wish to learn by performing the experiment.

For an absolute distinction between particles and anti-particles a comparison between the interference experiment performed terrestrially (defined as composed of matter) and on some distant world must be made. From the sign of the interference term it is possible to decide whether this distant world is composed of matter or anti-matter.

To avoid arbitrariness in the definition of the symmetric and anti-symmetric combinations of neutral kaons, we take as the first component of both combinations that neutral kaon produced by associated production of pions on local matter. On a world composed of matter (anti-matter) this gives the combinations of equations (1) and (5).

The $\pi^+\pi^-$ intensity is given from Eq. (5) for $\bar{K}^0$ decay on an anti-world (a world composed of anti-matter) by:

$$I'(\tau) = I_0 \left\{ e^{-\Gamma_S \tau} + |\eta'_{+-}|^2 e^{-\Gamma_L \tau} + \right.$$

$$\left. + 2|\eta'_{+-}| e^{-(\Gamma_S + \Gamma_L)\tau/2} \cos\left[(m_S - m_L)\tau + \phi'_{+-} \right] \right\} \qquad (6)$$

Note that it has the identical form as (4) for K^0 decay on a world. However, the absolute distinction between particles and anti-particles results from observing that, although

$$|\eta'_{+-}| = |\eta_{+-}|$$

the phase

$$\phi'_{+-} = \phi_{+-} \pm \pi \ .$$

Then, if the phase at $\tau = 0$ of the interference term for the experiment performed on a distant world matches the phase for the experiment performed terrestrially, then this distant world is composed of matter. If it is π out of phase, then this distant world is composed of anti-matter.

An alternate method for observing $\pi^+\pi^-$ interference is by the use of a regenerator. This has the experimental advantage that the interference term can be adjusted to match the background term, whereas in equations (4) or (6) the interference term is much smaller than the background ($|\eta_{+-}| = 1.992 \times 10^{-3}$).[5] As performed on a distant world the K_L^0 beam after passing through a regenerator (composed of matter) is:

$$|\psi(\tau)> = |K_L^0> e^{-i(m_L - i\Gamma_L/2)\tau} + \rho\ K_S^0> e^{-i(m_S - i\Gamma_S/2)\tau} \quad . \qquad (7)$$

The $\pi^+\pi^-$ intensity is given by:

$$\tilde{I}(\tau) = \tilde{I}_0 \Big\{ |e|^2 e^{-\Gamma_S \tau} + |\eta_{+-}|^2 e^{-\Gamma_L \tau} + + 2|\rho||\eta_{+-}| e^{-(\Gamma_S + \Gamma_L)\tau/2} \cos\left[(m_S - m_L)\tau + \phi_{+-} + \phi_\rho\right]\Big\}, \qquad (8)$$

with $\phi_\rho = \arg\,[i\,[f(K^0 n) - f(\bar{K}^0 n)\,]\,]$, where $f(K^0 n)$ is the forward scattering amplitude of K^0 on the nucleons of the regenerator. The regenerator is assumed thin for simplicity. As performed on an anti-world with a regenerator composed of anti-matter the $\pi^+\pi^-$ intensity is:

$$\tilde{I}'(\tau) = \tilde{I}_0 \Big\{ |\rho'|^2 e^{-\Gamma_S \tau} + |\eta_{+-}|^2 e^{-\Gamma_L \tau} + + 2|\rho'||\eta_{+-}| e^{-(\Gamma_S + \Gamma_L)\tau/2} \cos\left[(m_S - m_L)\tau + \phi'_{+-} + \phi'_\rho\right]\Big\} \quad . \qquad (9)$$

with

$$\phi'_{\rho} = \arg \left[i \, [f(K^0 n) - f(K^0 n)] \right] .$$

From charge conjugation invariance of the strong interactions $\phi'_{\rho} = \phi_{\rho}$. The absolute distinction between particles and anti-particles, as in the previous case, is then dependent on the phase ϕ_{+-} or ϕ'_{+-}.

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