UCRL-11507

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A PROPOSED ANALYSIS OF K_1^0-K_2^0 MASS DIFFERENCE EXPERIMENTS

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Submitted to Physics Letters

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AEC Contract No. W-7405-eng-48

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Is the Parity of the K^0 Meson Imaginary? A Proposed Analysis of $K_1{}^0$-$K_2{}^0$ Mass-Difference Experiments*

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If all parity-conserving reactions conserve strangeness, the title question is meaningless. The parity of the K^0 relative to the vacuum is, in that case, unmeasurable in principle. If on the other hand, as R. Spitzer suggests[1, 2]), there is a sequence of parity-conserving reactions

$$K^0 \to K^0 + \gamma \to K^0 + \gamma + \gamma' \to \overline{K}^0 + \gamma' + \gamma'' \to \overline{K}^0 + \gamma' + F \to \overline{K}^0 \qquad (1)$$

that involve only gamma rays and an external field, F, the question becomes meaningful.

If present, sequence (1) carries K^0 into $\overline{K}^0$, competes with the weak $\overline{K}^0 \to \overline{K}^0$ transition, and contributes a term depending on the external field to the measured $K_1{}^0$-$K_2{}^0$ mass difference. In particular, if we start with a pure K^0 state at time $t=0$, at time t the fraction of $\overline{K}^0$ present is

$$P(\overline{K}_0;t) = \frac{1}{4}\left[\exp(-\gamma_1 t) + \exp(-\gamma_2 t) - 2\exp(-\gamma t)\cos\omega t\right],$$

where γ_1 and γ_2 are the inverse lifetimes of the K_1 and K_2, $\gamma=(\gamma_1+\gamma_2)/2$, and ω is the $K_1{}^0$ - $K_2{}^0$ mass difference in appropriate units.

If a Spitzer-type reaction occurs, ω is not constant but depends linearly on the external magnetic field as follows, if the effect is small:

* Work sponsored by the U. S. Atomic Energy Commission.

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$$\omega = \gamma_1 [a_0 + a_1 (\underset{\sim}{K} \cdot H) + a_2 (E \cdot H)],$$

Where $\underset{\sim}{K}$ is a unit vector in the direction of the original K^0 trajectory, and E and H are the external electric and magnetic fields.

In bubble chambers, neutral kaons are commonly produced in secondary reactions and emitted at different angles relative to an external magnetic field. Therefore since $\underset{\sim}{K} \cdot H$ is different for each observed event, we suggest that the proposed dependence of the $K_1^0 - K_2^0$ mass difference, ω, on $\underset{\sim}{K} \cdot H$ be investigated, particularly in those experiments that have already been performed. An appropriate calculation for these purposes is given in the Appendix.

The pseudoscalar character of the $\underset{\sim}{K} \cdot H$ and $E \cdot H$ terms determines (if the reaction occurs) that the relative intrinsic parity of K^0 and $\bar{K}^0$ is negative. If we assume space inversion to be a local transformation, then the product of the intrinsic parity of a spin-zero particle and that of its antiparticle is +1:

$$\eta(K^0) \times \eta(\bar{K}^0) = 1.$$

The experimental conclusion that

$$\eta(K^0) = -\eta(\bar{K}^0)$$

would imply then that the intrinsic parity of the K^0 is imaginary:

$$\eta(K^0) \times \eta(\bar{K}^0) = 1 = -\eta(K^0) \times \eta(K^0)$$

$$\eta^2(K^0) = -1.$$

The intrinsic parities of the Λ and Σ must also be imaginary, in this case, relative to that of a nucleon of appropriate charge to achieve consistency with experiment. If we start with imaginary parities for the K, Λ, and Σ, it follows that parity-conserving reactions of pions and nucleons must produce such particles in pairs. Further, decay of such a particle into states of pions and nucleons alone cannot conserve parity.

From this point of view, then:

1. Conservation of strangeness in associated production reactions, is explained by parity conservation alone.

2. Failures of strangeness conservation by odd numbers in parity-conserving reactions, are forbidden by parity conservation alone.

3. Conversely, failure of parity conservation in the decay, for example, of a K meson into π mesons is attributed to the imaginary parity of the former and the real parity of the latter, and is thus almost a tautology under these assumptions.

4. The nonoccurrence of reactions having even strangeness changes remains unexplained (e.g., $\pi^- + p \rightarrow \Sigma^+ + K^-$).

Apart from the experimental and statistical difficulties in determining if a significant result not attributable to fluctuations has been found, there are two other complications.

First, there may be a real $\underset{\sim}{K} \cdot H$ dependence that does not have the implications of the one postulated by Spitzer. The essential feature is the absence of scalar terms like $\underset{\sim}{K} \cdot E$. Whatever the parity-conserving mechanism, the presence of pseudoscalar and absence of scalar terms lead to the same conclusion. If a $\underset{\sim}{K} \cdot H$ dependence is found, the absence of a $\underset{\sim}{K} \cdot E$ term should be checked deparately.

Second, the coefficient α_1 contains a complicated kinematic dependence on p^2, p'^2 and $p\,p'$ whose form has not yet been calculated, where the unprimed variable refers to the K^0 and the primed, to the $\overline{K}^0$. Specifically, the matrix element for process (1) is proportional to [2])

$$\beta_2 = \epsilon_{\mu\nu\rho\sigma} f_{\rho\sigma} p'_\mu p_\nu C_2 \approx -2i\, C_2 \left[p_0 H \cdot (\overline{p} - \overline{p}') + (\overline{p}' \times \overline{p}) \cdot E\right].$$

Since we examine only $\overline{K}^0$'s emitted in the forward direction, only the first term on the right survives. The complicated kinematic dependence mentioned above is contained in C_2, and $\underline{K}$ is a unit vector in the direction $\overline{p} - \overline{p}'$. The strength of the coupling associated with reaction (1) might be poorly estimated from α_1 because of this radical averaging over kinematic quantities.

APPENDIX: CALCULATION OF DEPENDENCE OF K_1^0 - K_2^0 MASS DIFFERENCE ON EXTERNAL MAGNETIC FIELD BY USING THE MAXIMUM-LIKELIHOOD METHOD

We perform the calculation using the MINFUN computer program[3]) as specialized to the particular calculation given below. (The calculations are programmed in Fortran IV language and will be made available on request).

Assume that the probability that a $\overline{K}^0$ will undergo a detectable identifying reaction in the proper time interval t, t + dt is $\lambda(t)dt$. Then an unbiased likelihood function for a given event is proportional to

$$\ell'_i = P(\overline{K}_0 ; t_i) \,/\, \int_0^{T_i} P(\overline{K}_0 ; t)\lambda(t)dt,$$

where t_i is the proper time at which the $\overline{K}^0$ is detected, and T_i is the latest proper time at which the $\overline{K}^0$ could have been detected.

If $\lambda(t)$ is independent of time (assume that the $\overline{K}^0$ momentum is constant), the likelihood functions ℓ_i' will achieve maxima for the same values of α_0, α_1, and α_2, independent of λ. Thus we can ignore λ and work with

$$\ell_i = P(\overline{K}_0 ; t_i) \,/\, \int_0^{T_i} P(\overline{K}_0 ; t)dt.$$

We then have

$$\ell_i = N_i/D_i$$

where

$$N_i = \exp(-\gamma_1 t_i) + \exp(-\gamma_2 t_i) - 2\exp(-\gamma t_i)\cos\omega_i t_i,$$

$$D_i = [1-\exp(-\gamma_1 T_i)]/\gamma_1 + [1-\exp(-\gamma_2 T_i)]/\gamma_2 - 2G_i/(\gamma^2+\omega_i^2),$$

and

$$G_i = \gamma + (\omega_i \sin\omega_i T_i - \gamma\cos\omega_i T_i)\exp(-\gamma T_i).$$

The total likelihood function is $\ell = \prod_i \ell_i$. The function we treat is $f = -2\log\ell$, which has a minimum where ℓ has a maximum (enabling us to use MINFUN, a program that seeks function minima) and corresponds to the χ^2 parameter. For calculating such minima, the derivatives of f are needed:

$$\frac{\partial f}{\partial a_j} = -2\sum_i \frac{\partial\omega_i}{\partial a_j}\left(T_i^{(1)} + T_i^{(2)}\right),$$

where

$$T_i^{(1)} = [t_i \sin\omega_i t_i \exp(-\gamma t_i)]/N_i$$

and

$$T_i^{(2)} = \{2/[D_i(\gamma^2+\omega_i^2)^2]\}\{(\gamma^2+\omega_i^2)\exp(-\gamma T_i)[\sin\omega_i T_i(1+\gamma T_i)] + \omega_i T_i \cos\omega_i T_i - 2G_i\omega_i\},$$

with

$$\omega_i = \gamma_i[a_0 + a_1(\underset{\sim}{K}\cdot H)_i + a_2(E\cdot H)_i].$$

ACKNOWLEDGMENT

The author wishes to thank Dr. Richard Spitzer for useful discussions over a period of several years.

REFERENCES

1) R. Spitzer, Nucl. Phys. 21 (1961) 681.

2) R. Spitzer, Nucl. Phys. 47 (1963) 367.

3) W. E. Humphrey, MINFUN, Alvarez Group Programmer Note P6, Lawrence Radiation Laboratory, Berkeley, California (unpublished).