CM-P00056854

THE LEE THEORY OF INTERMEDIATE BOSONS AND THE $K \ell_3$ DECAYS

J.S. Bell, Ph. Meyer ^{*)} and J. Prentki

CERN, Geneva

^{*)} On leave from the Laboratoire de Physique théorique
et des hautes énergies - Orsay.

T.D. Lee ¹⁾ has recently proposed a theory of weak interactions mediated by vector bosons. We shall show that this theory is in contradiction with present experimental results on the leptonic decays of kaons. In fact a whole class of theories, of which this is a member, can be dismissed if the present data are correct.

The theory is designed to incorporate the following features :

- a) the $|\Delta I| = \frac{1}{2}$ rule for non-leptonic decays;
- b) the presence of both $\Delta I = \frac{1}{2}$ and $\Delta I = \frac{3}{2}$ currents in leptonic decays ²⁾;
- c) no $\Delta S = 2$ contributions in either leptonic or non-leptonic decay.

It is assumed that the bosons form an isobaric triplet with charges $+, 0, -$. But of course isospin is not conserved. A simple method to deal with this is to introduce an isospinor spurion amplitude $x = (0, 1)$, and to require that with the help of this the Hamiltonian can be written formally as an isoscalar. If W is the isovector field representing the boson, a possible Hamiltonian would be for example

$$\begin{aligned}
 H = & g \bar{N} \underline{\tau} N \cdot \underline{W} + g_{\Sigma} (\bar{N} \underline{x}) \underline{\Sigma} \cdot \underline{\pi} + i g'_{\Sigma} (\bar{N} \underline{\tau} \underline{x}) \cdot \underline{\Sigma} \times \underline{\pi} \\
 & + g_{\Lambda} (\bar{N} \underline{\tau} \underline{x}) \cdot \underline{W} A + \text{Hermitian conjugate} .
 \end{aligned}
 \tag{1}$$

This gives features a) and b) above, and for c) it is sufficient that bosons and antibosons form distinct triplets, $W \neq \bar{W}$. There are then six bosons, and the Hamiltonian (1) is essentially that of Lee.

2.

Such a theory has many attractive features. But consider now, in this theory, the leptonic decay rates of kaons. The effective Hamiltonian for $K \rightarrow W + \pi$ must have the general form ³⁾

$$A(\bar{\chi} \gamma_\mu K) \pi \cdot W^\mu - i B(\bar{\chi} \gamma_\mu K) \cdot \pi \times W^\mu \quad (2)$$

For the interaction of W with leptons, following Lee, we take ⁴⁾

$$H_\ell = f(\bar{e} \nu W_- + \bar{\nu} e W_+ + \bar{\mu} \nu W_- + \bar{\nu} \mu W_+) \quad (3)$$

+ Hermitian conjugate.

The effective Hamiltonian for the over-all process, $\Delta S = -1$ decays into electrons or positrons, is obtained from (3) (apart from a common factor) by the substitutions

$$\begin{aligned} \bar{W}_- &= \bar{W}_1 + i \bar{W}_2 \rightarrow \bar{\psi}_\nu i \gamma_\mu (1 + \gamma_5) \psi_e \\ \bar{W}_+ &= \bar{W}_1 - i \bar{W}_2 \rightarrow \bar{\psi}_e i \gamma_\mu (1 + \gamma_5) \psi_\nu \\ \bar{W}_0 &= \bar{W}_3 \rightarrow 0 \end{aligned}$$

Assuming CP invariance, the $\Delta S = +1$ effective Hamiltonian can then be inferred. Under CP, $K_0 \rightarrow \bar{K}_0$ (by convention), $W_{+,0,-} \rightarrow +W_{-,0,+}$

[from (1)] and $\pi_{+,0,-} \rightarrow -\pi_{-,0,+}$. For positron decays the following interaction results

$$\bar{\Psi}_\nu i \gamma_\mu (1 + \gamma_5) \Psi_e \left\{ A (\pi_+ \partial_\mu K_0 + \pi_+ \partial_\mu \bar{K}_0) + B (\pi_+ \partial_\mu K_0 - \pi_+ \partial_\mu \bar{K}_0 - \sqrt{2} \pi_0 \partial_\mu K_+) \right\} \quad (4)$$

From this one obtains the following relative decay amplitudes

$$K_0 \rightarrow \pi^- e^+ \nu : A + B$$

$$\bar{K}_0 \rightarrow \pi^- e^+ \nu : A - B$$

$$K^+ \rightarrow \pi^0 e^+ \nu : -\sqrt{2} B$$

With $K_{01} = (K_0 + \bar{K}_0)/\sqrt{2}$ and $K_{02} = (K_0 - \bar{K}_0)/i\sqrt{2}$, and because CP invariance implies that

$$\Gamma(K_{01} \rightarrow \pi^+ e^- + \bar{\nu}) = \Gamma(K_{01} \rightarrow \pi^- e^+ + \nu)$$

$$\Gamma(K_{02} \rightarrow \pi^+ e^- + \bar{\nu}) = \Gamma(K_{02} \rightarrow \pi^- e^+ + \nu)$$

we have the following predictions on total electronic decay rates :

$$\frac{\Gamma(K_{01} \rightarrow \pi^+) + \Gamma(K_{01} \rightarrow \pi^-)}{\Gamma(K_{02} \rightarrow \pi^+) + \Gamma(K_{02} \rightarrow \pi^-)} = \left| \frac{A}{B} \right|^2 \quad (5)$$

$$\frac{\Gamma(K_{02} \rightarrow \pi^+) + \Gamma(K_{02} \rightarrow \pi^-)}{\Gamma(K^+ \rightarrow \pi^0)} = 2 \quad (6)$$

The second of these formulae is the same as in the old $|\Delta I| = \frac{1}{2}$ theory. One way to change it would be to couple the leptons unequally to $\bar{W}_-$ and $\bar{W}_+$. This is not very attractive, for reasons already given ⁴⁾.

The present experimental value of the ratio (6) is ²⁾

$$\frac{9.3 \pm 2.5}{8.2 \pm 0.6} = 1.1 \pm 0.3 .$$

Actually these numbers include also the muonic decay rates, but this would not alter the theoretical ratios (5) and (6). There seems to be definite disagreement, and if the experiments are confirmed, the theory must be rejected. It is therefore highly desirable to have more precise data on these $K \rightarrow \pi \ell \nu$ decays, which probably constitute the most direct test of the proposed theory.

We conclude with some remarks on the more general class of theories of which Lee's is an example. Suppose we take very seriously (despite recent evidence ²⁾) the $|\Delta I| = \frac{1}{2}$ rule of non-leptonic decays. Then it is certainly natural to extend the idea of isospin to the bosons, and one may suppose that

bosons and antibosons form single isobaric multiplets. Assuming the rule $\Delta I = 0$ or $\frac{1}{2}$ for the boson emission and absorption processes leads to the Hamiltonian

$$\sum W_i J_i + \sum W_i x_j J_{ij} + h.c. \quad (7)$$

Here the W_i are the isospin components of the boson field, the J 's are currents (non-leptonic for the moment) with which they interact, and x is the spurion isospinor which can be regarded as absorbing unit strangeness. The Hamiltonian is required to be formally isoscalar. The bosons W and antibosons $\bar{W}$ are distinct. Finally the charged bosons are coupled to lepton pairs to permit leptonic decays.

For bosons of isospin I the currents of the first term in (7) have isospin I and those in the second have isospin $I \pm \frac{1}{2}$. Currents of isospin $\frac{1}{2}$, 1, and $\frac{3}{2}$ are required in leptonic decays²⁾. This fixes the value $I = 1$ ⁵⁾. The isovector current must have zero strangeness, and therefore so also must the bosons⁶⁾. This is then just the theory of Lee. So of this class of theories, in which bosons and antibosons form single isobaric multiplets, etc., the Lee theory is uniquely selected by the qualitative data. Its quantitative failure would signal the failure of this whole approach. From this point of view the study of $K \rightarrow \pi e \nu$ decays is decisive for a whole class of intermediate boson theories.

FOOTNOTES AND REFERENCES

- 1) T.D. Lee, Phys.Rev. Letters 9, 319 (1962).
- 2) See, e.g., the report of F.S. Crawford in the Proceedings of the 1962 International Conference on High-Energy Physics at CERN.
- 3) For simplicity, we have written an effective Hamiltonian. The same reasoning could be made with the most general matrix element without altering the result. In that case the "constants" A and B are functions of the invariant square of the kaon-pion momentum transfer. For brevity we have also omitted in (2) possible terms where ∂_μ acts on W rather than K ; they would not affect the conclusion.
- 4) The Hamiltonian (3) for leptonic interactions is not strictly necessary. One could generalize it to

$$f_1 (\bar{e} \gamma + \bar{\mu} \gamma) W_- + f_2 (\bar{\nu} e + \bar{\nu} \mu) W_+ + h.c.$$

μ decay would then be proportional to $f_1^2 + f_2^2$ whereas β decay would be proportional to $\sqrt{2}g (f_1 + f_2)$. However, in such a theory the universal Fermi interaction would come out as a pure accident which is highly unsatisfactory.

- 5) If one abandons the requirement of the presence of $\Delta I = \frac{3}{2}$ leptonic currents, we have also the possibility of $I = \frac{1}{2}$. This is nothing else than the "schizon" scheme of Lee and Yang.
- 6) T.D. Lee ascribes strangeness ± 1 to the bosons. This is also possible of course, since strangeness is not conserved. However, strangeness zero should be used when the bosons are described as isovector to preserve the usual relation $Q = I_3 + \frac{U}{2}$.