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A NOTE ON THE ELECTROMAGNETIC MASS OF K-MESON

It has been established in the recent experimental works of Rosenfeld etc.[1], and Crawford etc.[2], that the neutral K-meson is heavier than the charged one:

$$m_{K^0} - m_{K^+} = 4.8 \pm 1.1 \; Mev , \quad m_{\tilde{K}^0} - m_{K^-} = 4.7 \pm 1.3 \; Mev \tag{1}$$

At first sight this result seems to be in contradiction with the fact that K^+ and K^0 are spinless particles, belonging to the same charge doublet. Actually, if K^0 doesn't interact with the electromagnetic field and the mass difference is of electromagnetic nature, one might expect that the charged K-meson should be heavier (see e.g.[3]) due to its electromagnetic self mass.

On these grounds the authors of works [1,2] have suggested, that their result may be considered as an evidence in favour of the Pais hypothesis[4], that K^+ and K^0 do not form charge doublet and have different intrinsic parities.

In the present note we shall show that there are no sufficient grounds to draw this conclusion. Namely, mass-difference (1) can be explained inside the usual multiplet scheme of Gell-Mann-Mishijima, if the electromagnetic interaction of K^0-meson is taken into consideration.

In fact, as has been noticed by G. Feinberg in his interesting paper[5], the neutral spinless particle which is different from its antiparticle, can interact with electromagnetic field. Such an interaction will arise from the virtual dissociation of K^0-meson into e.g. nucleons and antihyperons.

Then K^0-meson will possess the electromagnetic structure.

The lagrangian for the gauge invariant electromagnetic interaction can, in general, be written in the form

$$L = - \int d^4x \, j_\mu(x) A_\mu(x) \tag{2}$$

where $j_\mu(x)$ is the operator of the total current of all strong interacting particles. Then, in β-formalism of Duffin-Kemmer the matrix element between one-K-meson states has the form *)

$$\langle p' | j_\mu(x) | p \rangle_K = - \frac{ie}{(2\pi)^3} \exp(-iqx) \bar{\mathcal{U}}(p') \beta_\mu \left(F_{1K}(q^2) + \tau_3 F_{2K}(q^2) \right) \mathcal{U}(p) \tag{3}$$

where $q = p' - p$; p' and p are 4-impulses of K-meson in the final and initial states respectively; $\bar{\mathcal{U}}(p') = \mathcal{U}^+(p')(2\beta_4^2 - 1)$ and $\mathcal{U}(p)$ are the corresponding wave functions of K-meson in β-formalism; $F_K(q^2)$-form factors:

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* As noticed in[5], for π^0-meson, which is truly neutral such a matrix element vanishes because of the invariance under charge conjugation.

$$F_{K^+}(q^2) = F_{1K}(q^2) + F_{2K}(q^2), \quad F_{K^0}(q^2) = F_{1K}(q^2) - F_{2K}(q^2) \tag{4}$$

$$F_{K^+}(0) = 1, \quad F_{K^0}(0) = 0 \tag{5}$$

as the charge of the particles is equal to $eF(0)$.

The self mass of K-mesons due to electromagnetic interactions (2),(3) is equal to

$$\Delta m_K = \frac{ie^2}{(2\pi)^4}\frac{1}{\bar{v}v}\,\bar{v}(p)\int\frac{d^4q}{q^2}\beta_\nu\left[\frac{i(\hat{p}-\hat{q})+\frac{1}{2m}(\hat{p}-\hat{q})^2}{(p-q)^2+m^2}-\frac{1}{m}\right]\beta_\nu\left[F_K(q^2)\right]^2 \tag{6}$$

$$= \frac{ie^2}{2(2\pi)^3 m}\int d^4q\,\frac{\left[F_K(q^2)\right]^2}{q^2}\left[\frac{(2p-q)^2}{(p-q)^2+m^2}-4\right] \tag{7}$$ *

$F_{1,2K}(q^2)$ as a function of q^2 can be determined only by precise theory which does not exist at present or from a full analysis of future experiments. Since our purpose is to show only, that the mass difference found in [1,2] may be of electromagnetic nature, we shall take for example

$$F_{K^+}(q^2) = \frac{16m^4}{[q^2+4m^2]^2}, \qquad F_{K^0}(q^2) = -\frac{4\lambda q^2 m^2}{[q^2+4m^2]^2} \tag{8}$$

Then we obtain for the mass-difference from (7) and (8) the expression

$$m_{K^0} - m_{K^+} = \frac{m_K}{2\pi}\,\alpha\left(\frac{7}{3}\lambda^2 - 1\right) \tag{9}$$

Comparing it with the experimental value $\sim 4{,}8$ MeV we find $\lambda \simeq 2$. It is worth while to note the difficulty of observing other effects of the electromagnetic interaction of K^0.**

Thus, there is no compelling reason to deny existing charge multiplet theory of Gell-Mann and Nishijima since both the sign and the magnitude of the mass difference found in [1,2] can be accounted for by the electromagnetic interaction.

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* Expression (7) for the self mass can be obtained also from the usual theory, where K-meson is discribed by Klein-Gordon equation and electromagnetic interaction is introduced in the gauge invariant way, by substitution $\frac{\partial}{\partial x_\mu} \to \frac{\partial}{\partial x_\mu} - ieF(-\Box)A_\mu$

** As noted in [5], bremsstrahlung of K^0 is absent and it is very difficult to distinguish between the electromagnetic scattering of K^0 and the nuclear one. The most characteristic experiment is to find energetic δ-electrons along the path of K^0-meson. However, the cross section of K^0 - e scattering is small for low energies. Even for K^0-meson of 1 BeV energy in laboratory system the effect will be negligibly small, as in C.M.S. of K^0 - e the energy is of the order 1 MeV.

References

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