During the past few years masses obtained by these two methods have appeared to differ systematically. Both methods require the use of the so-called range-energy curves, and all three groups referred to have used the results of Aron, Hoffman, and Williams.[4] The Paris group has pointed out that an error in the range-energy curves would affect the masses deduced by the two methods described above in opposite senses.

The recent work of several authors[5–8] indicates that for copper and lead, the stopping materials primarily used in the multiplate cloud-chamber experiments, a more suitable value of the mean excitation potential I would be $I=13.0Z$. In particular, the values of Bichsel and Mozley were: for Cu, $12.9Z$; and for Au, $13.1Z$ (corrected for K-shell electron effects, using protons of energy 6 to 18 Mev). When this new value of I is used, the range-energy curves shift in such a way that for a given mass and momentum, the range is increased by 1.6 percent. The several mass values available have been reconsidered on this basis.

The values of the Paris group[1] were as follows:

(a) $906\pm27m_e$ for an average of six events measured by method 1, where the secondary range was such as to require a μ meson, thus indicating a K_μ particle.

(b) $928\pm12m_e$ for an average of 22 events measured by method 1 not necessarily all K_μ's, thus indicating an upper limit to the K_μ mass.

(c) $941\pm11m_e$ determined by method 2 on the basis of nine events.

The value of the M.I.T. group for determination of the mass by method 2 was:

$948\pm15m_e$ based on the best two events of their sample. (This mass was obtained by taking the range reported,[2] using a μ mass of 105.8 Mev, and the curves of reference 4.)

The change in the range-energy curves reported above results in raising masses of method 1 and lowering those of method 2. The new results are then:

Paris: 906 is increased to $915\pm27m_e$, (method 1)
928 is increased to $936\pm12m_e$, (method 1)
941 is decreased to $934\pm11m_e$, (method 2)
M.I.T.: 948 is decreased to $941\pm15m_e$. (method 2)

The Princeton results[3] have been reported, taking into account the effect of the range-energy changes. These results were:

$900\pm40m_e$ for method 1 on the basis of five events,
$912\pm15m_e$ for the backward S.

This result is less sensitive to the range-energy changes than those masses obtained by method 2, due to the fact that a measurement of a residual momentum was possible.

At this time there seems to be no systematic difference between masses obtained by the two methods and no systematic difference among the results of the various groups. Also, it appears that the $K_{\mu2}$ mass is significantly less than the τ mass. It is also of interest to note that the mass of the $K_{\pi2}$ reported by the M.I.T. group[2] is changed from 952 to $946\pm12m_e$ by the change in the range-energy results.

Further improvement in the interpretation of the range-energy results is under consideration. This involves the use of more recent improved shell corrections for both the K- and L-shells in the analysis of the experimental stopping-power data and in the calculation of the range-energy relation.

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[1] Armenteros, Gregory, Hendel, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento (to be published). We are indebted to B. Gregory for helpful discussions on the interpretation of these results, made available prior to publication.

[2] Bridge, DeStaebler, Rossi, and Sreekantan, Nuovo cimento (to be published).

[3] Ballam, Hodson, and Reynolds, preceding Letter [Phys. Rev. **99**, 1038 (1955)].

[4] Aron, Hoffman, and Williams, U. S. Atomic Energy Commission Report AECU 663 (unpublished).

[5] N. Bloembergen and P. J. van Heerden, Phys. Rev. **83**, 561 (1951).

[6] D. O. Caldwell and J. R. Richardson, Phys. Rev. **94**, 79 (1954).

[7] E. L. Hubbard and K. R. MacKenzie, Phys. Rev. **85**, 107 (1952).

[8] H. Bichsel and R. F. Mozley, Phys. Rev. **94**, 764 (1954). Also, private communication.

Gamma Stability of *K*-Mesons*

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ONE of the mysterious, and presumably significant, aspects of the heavy unstable particles is the remarkable clustering of masses in the neighborhood of 900–$1000m_e$.[1] The reasonably well-established decay processes in this mass range are

$$\tau^\pm \rightarrow \pi^\pm + \pi^+ + \pi^-,$$
$$\theta^0 \rightarrow \pi^+ + \pi^-,$$
$$\theta^\pm \rightarrow \pi^\pm + \pi^0,$$
$$K_{\mu2}{}^+ \rightarrow \mu^+ + \nu,$$
$$K_{\mu3}{}^\pm \rightarrow \mu^\pm + 2 \text{ neutrals},$$
$$K_{e3}{}^\pm \rightarrow e^\pm + 2 \text{ neutrals}.$$

The best-known mass is that of the τ meson ($965.5 \pm0.7m_e$)[2]; within the experimental errors this is identical with the mass of the θ^0 meson ($966\pm10m_e$).[3] The masses of the other particles are less well known, but there is some experimental indication that the $K_{\mu2}{}^+$ mass (estimated value $\sim940m_e$)[4] is distinctly below that of the τ meson. The estimated lifetimes for the various K-mesons lie in the range 10^{-10} to 10^{-8} sec.

If there exist among this group of K-mesons distinct particles with somewhat different masses, the question arises as to why the heavier members do not decay into the lighter members by photon emission. Since the lifetimes for the normal decay modes are so long, it might be expected that even with small mass differences such processes should compete favorably with the normal decay modes.

For example, even if the θ, τ, and γ are not directly coupled to one another, the θ and τ mesons are presumably strongly coupled to nucleons and pions, as evidenced by their copious production in collisions of these particles; and by the inverse processes they might therefore be expected to be strongly coupled to one another. The same remark holds for any other pair of K-mesons (perhaps $K_{\mu 2}^+$ and θ^+) which are strongly coupled to nucleons and pions in a similar way. In the "associated production" scheme of Gell-Mann,[5] for example, the θ and τ mesons would be expected to have the same isotopic spin assignments and would therefore be strongly coupled to one another. The situation with regard to the $K_{\mu 2}^+$ is much less certain, since there is little evidence regarding its mode of production or other charge states.

At any rate, in the discussion that follows we consider the possibility, still not excluded by experimental evidence, that two or more of the K-mesons are strongly coupled. Within this framework there are still several obvious ways to understand the absence of rapid decay by photon emission, each possibility being of some interest and being subject ultimately to experimental test.

(a) The strongly coupled K-mesons may have very nearly identical masses. This is especially indicated experimentally for the pair θ, τ; but it does not seem to be the case for the pair $K_{\mu 2}^+$, τ.

(b) If two particles both have spin zero, the decay of one into the other by single photon emission is of course absolutely forbidden. However, in this case one must also consider the possibilities of double photon decay and decay by the emission of an electron pair (the latter is possible only if both K-mesons have the same parity).[6] A rough estimate of the lifetime for either of these processes gives

$$T \sim \frac{1}{\alpha^2}\frac{R}{c}\left(\frac{\Delta M c}{\hbar}R\right)^{-7}. \qquad (1)$$

Here ΔM is the difference in mass between the two mesons; R is the range of the interaction, which we take to be of the order of a nucleon Compton wavelength, since the decay would likely take place via intermediate states involving particles of nucleonic mass; and $\alpha = 1/137$. Taking ΔM even as large as $25m_e$ (the indicated mass difference between the τ- and $K_{\mu 2}^+$-mesons) one finds $T \sim 1.5 \times 10^{-7}$ sec, which is longer than the lifetimes of the normal decay modes.

TABLE I. Values of $(2l+1)!!(2l-1)!![(\Delta Mc/\hbar)R]^{-(2l+1)}$.

l	$\Delta M = 10m_e$	$\Delta M = 25m_e$
1	1.9×10^7	1.2×10^6
2	9.5×10^{12}	9.5×10^{10}
3	1.1×10^{19}	1.8×10^{16}

(c) Another mechanism for inhibiting the decay by photon emission would be to assign very different spins to the strongly coupled K-mesons. A rough estimate of the lifetime for a 2^l-pole photon transition between strongly coupled K-mesons gives

$$T_l \sim \frac{1}{\alpha}\frac{R}{c}(2l+1)!!(2l-1)!!\left(\frac{\Delta M c}{\hbar}R\right)^{-(2l+1)}. \qquad (2)$$

The "natural" lifetime $(1/\alpha)(R/c) = 9.4 \times 10^{-23}$ sec. To effectively forbid the photon decay, the difference in spins of the two K-mesons must be chosen so that the l-dependent factors in Eq. (2) increase the lifetime to something greater than the 10^{-10} to 10^{-8} sec observed lifetimes for the normal decay modes. These factors are tabulated in Table I for two choices of ΔM. We see that even if the mass difference between $\theta^\pm$ and $\tau^\pm$ is as small as the present experimental error in the θ^0 mass ($\sim 10m_e$), and if both particles do not have spin zero, then the difference in spin must be at least two units. For the pair $K_{\mu 2}^+$ and τ^+, where as far as we now know the mass difference could be as large as say $25m_e$, the difference in spin would correspondingly have to be at least three units.

[*] Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] For a general discussion of recent K-meson results, see Proceedings of the Fifth Annual Rochester Conference (University of Rochester Press, to be published).

[2] See Report of the Padua Conference, Nuovo cimento **12**, Suppl. 2 (1954).

[3] Thompson, Burwell, Cohn, Huggett, and Karzmark, Phys. Rev. **95**, 661 (1954).

[4] See the summary by B. Rossi in reference 1.

[5] A summary of the Gell-Mann and Pais theories appears in the Proceedings of the International Physics Conference, Glasgow, 1954 (to be published).

[6] We would like to thank A. Pais and R. Dalitz for pointing out to us the possibilities of double photon and pair emission and for discussions of the estimate in Eq. (1).

Observations on the Charge and Mass Distributions in Nuclei

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RECENT measurements[1,2] of electric excitation cross section, σ_{ex}, and energy of first excited states, ΔE, gave different electric quadrupole moments,[1] Q_0, and electric quadrupole transition probabilities, $B(E2)$, using the Bohr-Mottelson theory[3] which