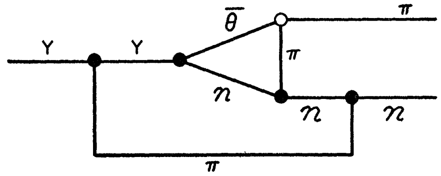

FIG. 3. Higher order diagram, "second assumption."

easily seen that the three branching ratios,

$$(\Lambda^0\rightarrow n+\pi^0)/(\Lambda^0\rightarrow p+\pi^-),$$
$$(\Sigma^+\rightarrow p+\pi^0)/(\Sigma^+\rightarrow n+\pi^+),$$

and

$$(\theta^0\rightarrow 2\pi^0)/(\theta^0\rightarrow \pi^++\pi^-),$$

should be equal in this approximation. In the case of the Σ^-, the neutral $\bar{\theta}$ channel is excluded by the conservation laws unless processes of still higher order, e.g., like Fig. 3, are taken into account. One would therefore expect the lifetime of Σ^- to be considerably longer than that of Σ^+.

If the transition $\theta^0\rightarrow 2\pi^0$ is parity-forbidden, the π^0 decay modes of both the Λ^0 and the Σ^+ should be very unlikely. This seems incompatible with the actual observation of several $\Sigma^+\rightarrow p+\pi^0$ events.[1,6] We conclude that the second assumption is tenable only if the θ has even parity and spin.

For the validity of our conclusions, it is essential that (1) the weak interaction (open circles) is treated as a first-order perturbation, (2) the strong interactions (black circles) are charge-independent (isotopic spin conservation), (3) charge exchange scattering of the two particles present after the decay is irrelevant. In addition, of course, the spins and parities of the particles involved must be such that the closed loops give nonzero matrix elements.[7]

Finally, it may be mentioned that the second assumption can be modified in such a way that only the θ^0 decays are elementary, whereas $\theta^+\rightarrow\pi^++\pi^0$ occurs as a higher-order process. Obviously, this makes no difference for the hyperon decays.

Note.—After this letter was written, Dr. Y. Nambu showed me a manuscript by Gyo Takeda in which similar results are derived from a different viewpoint (M. Goldhaber's hyperon model is used). In addition, Takeda develops other interesting arguments which may set limits for the branching ratios.

[1] York, Leighton, and Bjørnerud, Phys. Rev. **95**, 159 (1954).
[2] See also G. Costa and N. Dallaporta, Nuovo cimento **2**, 519 (1955).
[3] See R. W. Thompson, in *Progress in Cosmic Ray Physics* (North-Holland Publishing Company, Amsterdam, to be published), Vol. 3, Sec. 4.5.
[4] Ritson, Pevsner, Fung, Widgoff, Zorn, Goldhaber, and Goldhaber, Phys. Rev. (to be published).
[5] T. D. Lee and J. Orear, Phys. Rev. **100**, 932 (1955).
[6] Report by N. Dallaporta at the Fifth Annual Rochester Conference on High-Energy Physics (Interscience Publishers, Inc., New York, 1955), p. 82.
[7] The simplest admissible case is: $s_\theta=0^+$, $s_\Lambda=s_\Sigma=\frac{1}{2}^-$ ($s_\pi=0^-$, $s_{\mathfrak{N}}=\frac{1}{2}^+$). This also allows the Λ to be bound in hyperfragments; see G. Wentzel, Phys. Rev. (to be published).

Nature of the Neutral Particles in the $K_{\mu3}$ Decay*

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IN scanning a stack of emulsions exposed to the K^+ meson beam of the Bevatron, a K^+ meson was observed to decay at rest into two minimum-ionizing tracks (whose included angle is 5.3°) and a gray track; see Fig. 1. Multiple-scattering measurements on the two minimum-ionizing tracks gave $p\beta c$ values of 21 ± 6 and 74 ± 9 Mev respectively; for tracks at minimum ionization these values of $p\beta c$ can occur only for electrons, so that this pair of tracks represents an electron-positron pair. The other track, which is thus positively charged, is steeply dipping and was traced through 18 emulsions until it came to rest, having a total range of 7.94 mm. At the end of the track nothing is observed except possibly a slow electron.

Range *vs* ionization measurements on the positively charged secondary showed that it was produced by a light meson (i.e., either π^+ or μ^+); however, the track was too steeply dipping to differentiate between these two possibilities by means of the range-ionization measurements. The charged secondary underwent two scatterings of 25° and 41° at 56μ and 142μ residual range respectively. Since a 3-grain δ ray was observed at a residual range of 15μ, the charged particle at the very end of the track has a mass less than 450 Mev and it therefore cannot be a proton.[1] Each of the scatterings was analyzed and found to be inconsistent with a π-μ decay in flight and no other possible π-μ decay in flight was observed. Since the probability of not observing the π-μ decay of a π^+ meson of zero range is vanishingly small,[2] we conclude that our light meson is not a π^+. The only other alternative is that the track is that of a μ^+ meson. The fact that we do not observe the β^+ decay of the μ^+ is reconciled with the observation that in these emulsions the β^+ decay of a μ^+ is not observed in 15% of the cases.

We conclude that the emitted gray secondary is a μ^+ meson of 17.93-Mev kinetic energy at emission, and this is consistent with our ionization measurements. The mass of the decaying K^+ meson was determined to

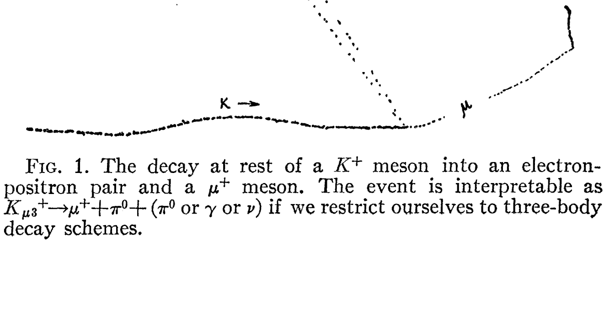

FIG. 1. The decay at rest of a K^+ meson into an electron-positron pair and a μ^+ meson. The event is interpretable as $K_{\mu3}^+\rightarrow\mu^++\pi^0+(\pi^0$ or γ or $\nu)$ if we restrict ourselves to three-body decay schemes.

be $(1060\pm200)m_e$ by momentum-range measurements. These values are quite consistent with the precisely measured mean mass of $(958\pm5)m_e$ for K^+ mesons[3] and we shall use this (latter) value in the discussion to follow.

We define a four vector $\tilde{P}_0$ with energy $E_0=E_++E_-=95\pm10$ Mev, and momentum $\mathbf{P}_0=\mathbf{P}_++\mathbf{P}_-$, whose magnitude is (94.92 ± 10) Mev/c; we can consider this as the energy-momentum four vector of a fictituous particle of rest mass $m_0=[(\tilde{P}_++\tilde{P}_-)^2]^{\frac{1}{2}}=3.7$ Mev and velocity $\beta_0=P_0/E_0=0.9991$ emitted at an angle to the μ^+ meson whose cosine is -0.245. If we first assume that the decay is $K_{\mu3}{}^+\rightarrow e^++e^-+\mu^++x$, application of the conservation laws determines the mass of x, $M_x=[(M_K-E_0-E_\mu)^2-(\mathbf{P}_0+\mathbf{P}_\mu)^2]^{\frac{1}{2}}$; we find $236<M_x$ (Mev) <265. Since no known particle of this mass exists, we conclude that the decay must involve at least two neutral particles; $K_{\mu3}{}^+\rightarrow e^++e^-+\mu^++y+z$. If we do not wish to invent a new interaction, the most plausible assumption (and indeed the only one that need concern us if we exclude the materialization of a real γ ray) for the source of an electron pair of this energy in this type of event is that it arises from the alternate decay of the $\pi^0\rightarrow e^++e^-+\gamma$. We thus have $K_{\mu3}{}^+\rightarrow\pi^0(\rightarrow e^++e^-+\gamma)+\mu^++z$. We can now set limits on the mass of z.

To obtain limits on M_z, we must first obtain limits on E_{π^0} and its angle of emission, θ, with respect to the resultant momentum $\mathbf{P}_0$ of the electron pair; $\cos\theta=\mathbf{P}_0\cdot\mathbf{P}_{\pi^0}/P_0P_{\pi^0}$. By squaring the equation $\tilde{P}_\gamma=\tilde{P}_{\pi^0}-(\tilde{P}_++\tilde{P}_-)$ (which represents the alternate π^0 decay) we obtain $\gamma(1-\beta\beta_0\cos\theta)=[(\mu_{\pi^0})^2+m_0{}^2]/(2\mu_{\pi^0}E_0)=A$, where $E_{\pi^0}=\gamma\mu_{\pi^0}$, $\beta=P_{\pi^0}/E_{\pi^0}$ and $\cos\theta$ is defined above. For the case $A<1$, which is of interest here, one can show by solving the above equation for β that $\beta\cos\theta\geqslant(1-A^2)^{\frac{1}{2}}$. We then obtain $\beta_{\max}=(1-A^2)^{\frac{1}{2}}$ for $\cos\theta=(1-A^2)^{\frac{1}{2}}/\beta_0$ and $\beta_{\min}=[\beta_0-A(A^2+\beta_0{}^2-1)^{\frac{1}{2}}]/(A^2+\beta_0{}^2)$ at $\cos\theta=1$. For our case, $0.645<A<0.796$ and we obtain $E_{\pi^0}(\min)=(\mu_{\pi^0}+3.5)$ Mev at $\cos\theta=1$ and $E_{\pi^0}(\max)=(\mu_{\pi^0}+74.5)$ Mev at $\cos\theta=0.763$. These limiting values of energy and angle are then used to obtain limits on M_z via the relation $M_z=[(M_K-E_\mu-E_{\pi^0})^2-(\mathbf{P}_\mu+\mathbf{P}_{\pi^0})^2]^{\frac{1}{2}}$. We find $0<M_z$ (Mev) <217. Thus it is possible for the missing neutral particle to be either a π^0 meson, a γ ray, or a neutrino.

The $K_{\mu3}{}^+$ decay is thus $K_{\mu3}{}^+\rightarrow\mu^++\pi^0+(\pi^0$ or γ or $\nu)$ if we restrict ourselves to three-body decays.[4] The existence of the π^0 meson among the decay products rules out the hypothesis[5] of a universal Fermi interaction to explain the $K_{\mu3}$ (and K_{e3}) decay scheme. If the $K_{\mu3}{}^+$ meson is a boson, as has been established for three of the four phenomenological decay modes, $K_{\pi2}{}^+$ (θ^+), $K_{\pi3}{}^+$ (τ^+), and $K_{\mu2}{}^+$, then the unknown neutral particle must be a neutrino and the decay is $K_{\mu3}{}^+\rightarrow\mu^++\pi^0+\nu$.

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1 In this way we rule out the possibility that one of the scatterings is a nuclear interaction of a π^+ meson from which a proton is ejected.

2 This probability is less than $0.15\times5\times10^{-5}$. The factor 0.15 is the probability of not seeing a high-energy electron in our plates and the factor 5×10^{-5} is the upper limit on the relative probability of the decay $\pi^+\rightarrow e^++\nu$ as reported by S. Lokanathan and J. Steinberger, Phys. Rev. **98**, 240(A) (1955).

3 D. M. Ritson (private communication). This value is relative to the τ-meson mass of $963m_e$; within experimental errors all K^+ mesons are found to possess the same mass.

4 The designation $K_{\mu3}$ is of course a phenomenological one, and there exists the possibility that those K particles classified as $K_{\mu3}$ in reality represent more than one distinct decay mode. If they represent one distinct decay mode, the observation of a μ meson of kinetic energy greater than 75.7 Mev but less than 152 Mev (corresponding to the μ meson from the $K_{\mu2}$ decay) would require the additional neutral particles (i.e., other than the π^0) to be massless.

5 Kaplon, Klarmann, and Yekutieli, Phys. Rev. **99**, 1528 (1955).

Energy Dependence of the Optical Model Parameters*

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We report some results of an analysis of proton elastic scattering at 5.25 and 31.5 Mev based on the diffuse surface optical model.[1] Together with results obtained previously at 17 Mev,[2] these provide some idea of the energy dependence of the optical model parameters. In this model, it is recalled, the nuclear part of the interaction between the incoming proton and the target nucleus is taken to be

$$-V(r)=\frac{V+iW}{1+\exp[(r-R_0)/a]},\tag{1}$$

and the Coulomb part of the interaction is chosen to be that appropriate to a uniform distribution of the nuclear charge over a sphere of radius R_0. We shall not present detailed comparisons between experimental and calculated cross sections at this time; we merely list the values of the optical model parameters which appear to give the best agreement with experiment.[3]

We first remark that R_0 and a, which describe the space dependence of the interaction, do not vary significantly with energy. Except for the lighter ele-