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SIMPLE CONSIDERATIONS RELATING STRANGE-PARTICLE LIFETIMES

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February 20, 1956

Considerations of phase space, final-state interactions, and selection rules can give a satisfying qualitative comparison of the decay rates R of different strange particles.

For example, if the matrix elements were equal, the decay rates R_Σ of the Σ and R_Λ of the Λ should be related by the available phase-space ratio $\rho(Q_\Sigma)/\rho(Q_\Lambda) \overset{\Lambda}{=} 2.5$,

where $\rho(Q) \propto p^2/(v_\pi + v_n)$.

Calculated ratios of phase space together with observed ratios of lifetimes are as follows:

Phase-space ratios		Observed lifetime ratios
1. $\frac{R(\tau \to 3\pi)}{R(\theta \to 2\pi)} = 10^{-4}$ to 10^{-3}	(Note a)	$\frac{R(\tau \to 3\pi)}{1/\tau_{\theta 0}} \approx \frac{\tau_{\theta 0}}{10\,\tau_\tau} \approx 10^{-3}$ (Note b)
2. $\frac{R(\Lambda \to n + \pi)}{R(\theta \to 2\pi)} = 1.1$	(Note c)	$\frac{\tau_{\theta 0}}{\tau_\Lambda} = 0.4^{+.3}_{-.1}$
3. $\frac{R(\Sigma \to n + \pi)}{R(\theta \to 2\pi)} = 2.6$	(Note c)	$\frac{\tau_{\theta 0}}{\tau_\Sigma} = 5^{+3}_{-2}$
4. $\frac{R(\Xi \to \Lambda \pm \pi)}{R(\theta \to 2\pi)} = 0.91 \times (2S_\Lambda + 1)$		$\frac{\tau_{\theta^0}}{\tau_\Xi} \simeq 1$
5. $\frac{R(\Sigma)}{R(\Lambda)} = 2.5$		$\frac{\tau_\Lambda}{\tau_\Xi} = 10 \pm 5$

a. The exact ratio depends upon the unknown size of the K meson. We have ignored the reduction of phase space imposed by conservation of angular momentum, because a crude estimate for spin-zero K particles shows that this reduction cannot be by more than a factor of two for the θ (if its radius is no larger than $\hbar/m_\pi c$), and has almost no effect on the τ.

b. The partial rate of decay of $\tau \to 3\pi$ is unfortunately not yet known. We know that (in emulsion, located 10^{-8} sec in proper time of flight from the Bevatron target) 7% of K mesons decay into three pions. If all K mesons were τ's capable of decaying into three pions, then $R(\tau \to 3\pi)$ would be 7% x $1/\tau_K$. But about 1/3 of all charged K's decay into two pions and hence are not τ mesons, so $R(\tau \to 3\pi) \geq 3/2 \times 7\% \times 1/\tau_K$. One of us (M. L. Stevenson, in "The Ratio of Lifetimes of Heavy Mesons and Hyperons as Predicted by Phase Space," UCRL-3275, Feb. 1956), has made an analysis of several possible decay schemes that would be consistent with experimental data, and finds that $R(\tau \to 3\pi) \sim 10\% \times 1/\tau_K$ is indeed a reasonable guess.

A smaller uncertainty occurs in the other lifetime ratios in this column, because the various parent particles are more easily sorted out.

c. Includes factor 2S nucleon + 1 = 2.

In the construction of the right-hand column of the table the neutral θ has arbitrarily been taken as the basis for comparison. With this choice all the calculated and experimental ratios are in qualitative agreement. But it is known that τ_{θ^+} is about 100 τ_{θ^0}.

To complete a satisfactory picture a way must be found to explain the hundredfold inhibition in $R(\theta^+)$. This has already been done,[1] provided that the θ has even parity, which is quite probable.[2] If the parity of the θ is even, then the final system of the two spinless bosons must be in a symmetric isospin state, i.e., I can be 0 or 2. Both states are available to the decay products of neutral θ, but of course $I = 0$ cannot represent a charged state and so is never available to the charged θ. Now it has been suggested[1] that there may be a selection rule for change in total isospin (in addition to I_z) in strange-particle decay; namely that the reaction may be further slowed down if $\Delta I > 1/2$. Accordingly the θ^0 (assumed to have $I = 1/2$) could decay into two pions in a state $I = 0$ as fast as any strange particle decays; but $\theta^+ \rightarrow 2\pi$ ($I = 1/2 \rightarrow I = 2$) would be inhibited. Since $\Delta I = 1$ can be achieved by electromagnetic forces, the inhibition may be a factor of $(1/137)$ to some small integral power, as compared with the factor of 100 which we need.[3]

We have shown that statistical factors, combined with a selection rule against large changes in total isospin, describe the most salient relative features of strange-particle decay rates. They also predict that there should be no fast reaction $\tau^0 \rightarrow 3\pi$ corresponding to $\theta^0 \rightarrow 2\pi$. It should be emphasized, however, that these general considerations can hardly explain why the mean life of the τ and the θ^+ are identical within 10%, as seems presently indicated.[4] According to our point of view $R(\tau)$ is relatively small because of phase-space limitations, while $R(\theta^+)$ is small for an entirely different reason, namely the proposed selection rule on I. It would be a real fluke if these two independent inhibitions made the θ and τ lifetimes exactly equal. As far as we can see, within the framework proposed here, only a cascade process such as proposed by Lee and Orear[5] would explain the "equality" of the τ and θ lifetimes.

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[1] R. Dalitz, private communication to Okubo and Marshak; also G. Wentzel (to be published); also S. Minami, Progr. Theoret. Phys. 14, 482 (1955).

[2] For example, Gell-Mann (in a private communication) and Lee and Yang (to be published) have assumed this in their parity conjugation schemes.

[3] Noting the availability of the $I = 0$ state to the θ^0 only, Okubo and Marshak (Bull. Am. Phys. Soc. 30, No. 8 (1955)), have proposed a different reason for the difference in lifetime between the θ^0 and the θ^+, namely that there may be a strong final-state interaction of the two pions for $I = 0$ and not for $I = 2$. This increases the θ^0 decay rate rather than slowing down the θ^+, so that it does not fit our needs as well as does the selection rule on total isospin.

[4] Fitch and Motley, to be published.

[5] Lee and Orear, Phys. Rev. 100, 932 (1955).

The selection rule inhibiting $\Delta I > 1/2$ also has some bearing on the relative decay rates of Σ's and Λ's. It is usually assumed that the Λ has $I = 0$; hence it would decay mainly into pion-nucleon states of $I = 1/2$. The Σ, on the other hand is assumed to have $I = 1$, so that it can decay not only into the $I = 1/2$ states available to the Λ but also into states of $I = 3/2$.[6] The availability of this extra state might account for the fact that R_{Σ}/R_{Λ} is experimentally ~10: 1 even though phase space accounts only for a factor 2.5.

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[6] Holliday (Bull. Am. Phys. Soc. II 1, No. 1, 51 (1956)), has already pointed out that if the Σ has $J = 3/2$ (+) then its decay rate into the $I = 3/2$ pion-nucleon state will be large compared with its rate into the $I = 1/2$ state.