On the Mean Lives of Heavy Unstable Particles.

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It is well known that one of the greatest difficulties in interpreting the properties of heavy unstable particles, which in these last years have been detected in a continuously increasing number of different types either in the cosmic radiation or in nuclear disintegrations artificially produced, consists in reconciling their relatively abundant production in the nuclear events, which is compatible with an interaction of the same order of magnitude as the interaction for $\pi$ production, with their long mean life, which should instead require a very weak interaction. This peculiar feature which is common to all unstable particles known up to date has recently been tentatively explained by Gell-Mann and Pais (1) in the following way: the strong interaction from which these "strange" particles originate (and also their electromagnetic interaction) are subject to special selection rules, which are correlated to conservation theorems imposed to a new internal coordinate of these particles, specially introduced for this purpose, and which act in such a way that they allow only those reactions in which two "strange" particles are produced together, while they forbid those reactions in which they should be produced singly.

These selection rules are supposed to act only on the strong nuclear and electromagnetic interactions, and not on other possible weak interactions, which could be responsible only in a very secondary way for exceptional cases of single production, and would instead be the only ones responsible for those decay processes, which are forbidden by the selection rules for the strong interactions. Some possible classification schemes and additional new quantum numbers attributed to the strange particles are proposed by the authors, from which, in the spirit of charge independence, it is possible to formulate those additional conservation theorem responsible for the new desired selection rules.

The aim of the present considerations is only to show how, in the framework of the Gell-Mann and Pais hypothesis, it is easy to deduce the right order of magnitude for the mean lives of the different kinds of "strange" particles by the

exclusive use of interaction constants already known from interactions of «normal» particles.

Let us consider first the group of forbidden reactions which can take place only through the weak interaction, and let us choose among them as representative the reaction: \( \text{N} + \text{N} \rightarrow \text{Y} + \text{N} \).

As the Gell-Mann Pais selection rules forbid that forces other than weak ones may act between two nucleons for the creation of a single hyperon, and as this reaction takes place between 4 fermions, it seems rather natural to assume that in this case the weak interaction should be the universal Fermi interaction between fermions, with interaction constant \( G \sim 2 \cdot 10^{-8} \text{ erg} \cdot \text{cm}^2 \).

The virtual inversion of this reaction allows us then to interpret the decay of an hyperon according to the following two-step process:

\[
\text{Y} \rightarrow \text{N} + \text{N} + \text{N} \rightarrow \text{N} + \pi
\]

which may be then described with the use of only the Fermi interaction constant and the \( g \) interaction constant between pions and nucleons.

For the sake of evaluating only the order of magnitude, it is sufficient to use scalar interactions with \( g^2/4\pi\hbar c = 0.25 \) and the drastic simplifications used by Fermi \(^2\) for the sums on the intermediate states. We get in this way for the transition probability per unit times \( w \):}

\[
w_L = \frac{0.11}{8\pi^4} \frac{G^2 M \rho^2}{\hbar^4} \frac{g^2}{4\pi\hbar c} \frac{c^3 p^2}{w(v_1 + v_2)}
\]

where \( M \) is the mass of the nucleon, \( p \) and \( w \) the momentum and total energy of the final pion, and \( v_1 \) and \( v_2 \) the velocities of the decay products.

For \( \Lambda_0 \) we obtain:

\[
\frac{1}{\nu_{\Lambda_0}} \sim 6.7 \cdot 10^{-10} \text{ s.}
\]

The same calculation for the \( \Sigma \) and \( \Xi \) particles, according to a similar scheme, would have given very similar results.

Let us take now as representative for the allowed strong interaction the process \( (K = \text{heavy boson}) \)

\[
\text{Y} \rightarrow \text{K} + \text{N}
\]

and let us suppose that in this case the interaction constant is the same as the \( g \) constant of the pions. This of course implies that the associated production of the heavy unstable particles will be of the same order of magnitude as the production of pions.

By inverting the reaction, we can now try to interpret the decay of the different \( K \) by the following 3rd order process:

for the $\theta$-decay:

\[(B)\] \[\theta \rightarrow Y + N \rightarrow Y + N + \pi \rightarrow \pi + \pi \]

and for the $\tau$ decay:

\[(C)\] \[\tau \rightarrow Y + N \rightarrow Y + N + \pi + \pi \rightarrow \pi + \pi + \pi + \pi \]

In both cases the transition $Y + H \rightarrow \pi$ is to be considered as equivalent to process (A) and defined by the constant:

\[
\frac{1}{2\pi \hbar c} \frac{\gamma^2}{4\pi^4} = \frac{0.1}{\hbar^8} \frac{G^2 M^4 c^2}{4\pi^3} \frac{\gamma^2}{\hbar^8} \frac{M}{4\pi^3}
\]

In case of the $\tau$-decay the emission of two pions in a single act is assumed to be more probable than and equivalent two step process in which the two $\pi$-mesons should be emitted in succession, according to the experimental Brookhaven evidence (a) on production of pions by 3 GeV energy protons.

In the same approximation as before, we get for the $\theta$-decay:

\[w_0 = \frac{0.044}{16\pi^2} \frac{1}{\hbar} \left( \frac{g_2^2}{\gamma^2} \right) \frac{\gamma^2}{2\pi^2 \hbar^8} \frac{M}{\mu_k} \frac{e^2 p^2}{c^2 w_v^2} \frac{c}{v_1 + v_2}
\]

with $\mu_k$ mass of the $\theta$, $w$ and $p$ energy and momentum of final $\pi$: which compared with (2) gives us:

\[\frac{w_0}{w_0} \sim 1.08 \cdot 10^{-3} \quad \text{hence} \quad \frac{1}{w_0} \sim 6.2 \cdot 10^{-7} \text{ s}.\]

For the $\tau$-decay, let us first try to form a tentative evaluation of the interaction constant for double pion production:

According to the statistical theory of Fermi (4) the ratio of the production cross-sections $\sigma_2$ and $\sigma_1$ for two and one pion in nucleon-nucleon collision, should be:

\[
\frac{\sigma_2}{\sigma_1} = \frac{1}{\Omega} \frac{\varrho(4)}{\varrho(3)} = \frac{3}{20},
\]

$V =$ Fermi volume, $\Omega =$ normalization volume: $\varrho(3)$ and $\varrho(4)$ statistical factors for 3 and 4 final reaction products.

According to Brookhaven data, this ratio is instead:

\[
\frac{\sigma_2}{\sigma_1} = \frac{1}{\Omega} \frac{\varrho(4)}{\varrho(3)} = \frac{3}{1} \quad \text{hence} \quad \frac{1}{V} \sim 20.
\]

Therefore we can interpret the creation of the second pion as if the interaction constant $g'$ in this case should be $g'^2 \approx 20 g'$.

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In the usual way we can then obtain for the mean life of the $\tau$:

\[ \tau^\tau = \frac{0.0044 \frac{1}{\hbar}}{32\pi^2} \left( \frac{g^2}{4\pi\hbar c} \right)^2 \left( \frac{\mu^2}{2\pi\hbar c} \right) \frac{M^2}{\mu\pi\hbar c} \]

and therefore

\[ \frac{\tau^\tau}{\tau^0} \sim 0.2, \quad \frac{1}{\tau^\tau} \sim 3 \times 10^{-6} \text{ s}. \]

If we had treated the problem by supposing that the three pions were produced in successive independent acts, we should have obtained a longer mean life by a factor of about $10^3$.

The formulae (2), (4), (6) do not represent as yet the true mean lives, as we have to sum over all the different intermediate states corresponding to different distributions of the charge between the different virtual particles and eventually also between the final states. For example, for the $\Lambda^0$, we have also to consider the possibility of the decay $\Lambda^0 \rightarrow N + \pi^0$, which can take place through 3 different ways of intermediate states, so that the lifetime turns out to be:

\[ \tau_\Lambda \sim \frac{1}{10} \frac{1}{\tau^\Lambda} \sim 0.67 \times 10^{-10} \text{ s}. \]

For the $0$ and $\tau$-particles it is more difficult to decide (as we are not yet sure how many of the hyperons we know are to be considered as intermediate states) the number of ways of decay over which we have to sum. Tentative estimates seem to indicate that we have to divide formula (3), (5) by factors of the order of $10^2$. These factors may have to be increased if we also try to apply isotopic spin formalism and consider the different possible charge states depending on it.

For example we obtain in this way for the order of magnitude of the $0$ and $\tau$ mean lives assuming $\Lambda^0$ and $\Sigma^\pm$ particles in intermediate states:

\[ \tau_0 \sim 10^{-8} \text{ s}, \quad \tau_\tau \sim 4.5 \times 10^{-8} \text{ s}. \]

These figures, though somewhat too large may be considered in rough agreement with the probable experimental values, owing to the very simplified procedure of calculation. These examples seem therefore to indicate that the Gell-Mann Pais theory should be able to fit the experimental data as concerns the mean lives of the particles without the introduction of any new type of interaction.