On the Nature of V-Particles, I

Y. Nambu, K. Nishijima and
Y. Yamaguchi

Department of Physics,
Osaka City University

June 19, 1951

Recently Butler et al.\textsuperscript{1)} presented further evidences concerning the nature of the so-called V-particles which had been observed by Rochester and Butler\textsuperscript{2)} and by Anderson and collaborators\textsuperscript{3)}. According to these authors: i) The V-particles are found among penetrating showers with a rate of the order of 1%; ii) Their decay life is estimated to be about $10^{-10}$ sec; iii) There are two kinds of them, charged and neutral, the latter being about 5 to 10 times more abundant than the former, presumably due to their difference in lives; iv) According to Butler et al., moreover, they can be
classified in two groups of different masses. The heavier particles, with mass about 2200 to 2300 \( m_n \), decay into a nucleon and a (\( \pi \)) meson, hence fermions. The lighter ones, with mass around 1000 \( m_n \), decay into two (\( \pi \)) mesons, and hence bosons; \( v \) One case is reported which shows a successive decay of a charged \( V \) through neutral \( V \) into three charged particles (three mesons or two mesons plus one proton), though no suggestion is given as to whether they belong to the heavier or the lighter group.

Then the arguments go on as follows. First of all, there is a possibility that the decay products of \( V \) and \( \tau \) might include \( \mu \)-mesons as well. This, however, seems rather improbable in view of the fairly large nuclear interaction of the decay mesons reported by Anderson et al., and the relatively long life of the parents in contrast to their sizable production rate. A three particle decay, such as \( V \rightarrow P + \mu + \nu \), is all the more unlikely according to Anderson et al.'s arguments about the coplanar character of the parent and daughter particles. It is also to be noted that soft showers are not associated with the \( V \) or \( \tau \) events, which shows that decays giving rise to photon or electron must be rare compared to the main processes. The above mentioned contradiction between production and decay may be lifted if we postulate, as was just the case in the \( \pi - \mu \) decay, that the observed \( V \) (though not necessarily including \( \tau \)) are decay products of some unknown particles with sufficiently short life and strong nuclear interaction. But at the present stage we will try to solve this problem using only the observed particles, assuming the decay products to be \( \pi \)'s and nucleons (of course excluding the case \( V \)). This can be done as follows:

Now we face two alternative interpretations of the point \( v \) above. One is to assume that the unknown particles involved in this reaction are \( V \)'s, decaying according to the scheme:

\[
V \rightarrow V_0 + \pi \pm, \quad V_0 \rightarrow N + \pi
\]

(\( N \)-nucleon) \( \quad (1) \)

while the other is to assume them to be \( \tau \)'s:

\[
\tau \rightarrow \tau_0 + \pi \pm, \quad \tau_0 \rightarrow 2\pi
\]

(\( \tau \)-emission can be forbidden energetically.) Such a situation has long since been anticipated in the strong coupling theory of nucleon-meson interaction. This theory however, does not just seem to be very useful for our analysis. For it is too crude and incomplete to be relied upon quantitatively, especially in view of the extremely small width of the actual levels (\( \sim 10^{-5}\)ev). In the present stage we had rather better treat them as different elementary particles, obeying Fermi statistics and having half-odd spins, possibly higher than 1/2, and introduce formal interactions which cause the observed transitions. Thus we assume the following scheme:

\[
\text{Interaction} \quad V_+ V_0 \pi, \quad V_0 N \pi, \quad V_+ N \pi, \quad V_0 N \pi
\]

Coupling const. \( G_1 \)

\[
VV \pi \quad NN \pi \quad VV \tau \quad NN \tau
\]

\( G_3 \); \( g_3 \) (known) \( G_4 \); \( g_4 \) \( \quad (3) \)

The conditions to be considered are: \( a \) decay life roughly all of order \( 10^{-10} \) sec.; \( b \) competition among various possible decay modes (especially for the \( \tau \)-decay process); and \( c \) production mechanism, to give a yield of \( \sim 10^{-1} \) times that of ordinary mesons.

For the calculation of \( \tau \rightarrow \pi + x (x=\pi, \gamma, \ldots) \) processes, the results of covariant calculation by many authors \( ^9 \) can directly be applied with only a few alterations. Unfortunately, however, most of the calculation involved are not free from the diverging ambiguities which have to be disposed of with the aid of the Pauli regulator. Accordingly, in the present order of magnitude consideration, we check them with more rough and intuitive
estimation which only takes account of the coupling constants and the volume of phase space — in a manner more or less similar to Fermi's.\textsuperscript{7} On the other hand, the various selection rules, such as described by Fukuda et al.\textsuperscript{8,9} are more reliable and can be used to narrow down the possibilities.

In this way we get the following results:

\[ G_1^2 \sim 10^{-11} - 10^{-13}, \quad G_2^2 \sim 10^{-2} - 10^{-4}, \]
\[ g_0^2 \sim 10^{-7} - 10^{-9} \]
\[ (G_3^2 \gtrsim g_2^2, \quad G_4^2 \approx g_2^2, \text{ not necessary). (4)} \]

The transformation property of \( \tau \) (or at least \( \tau_0 \)) must be either scalar or vector, since it is very likely that the \( \pi \) mesons are pseudoscalar.\textsuperscript{9} The range of values in (4) correspond to different assumptions as to Fermi's reaction volume (or alternatively the general trend of the covariant calculation), as well as the assignment of spin values for the \( V \) mesons. Thus discrepancies with experiment of the order, say, 100, should be tolerated.

Next let us examine the assumption (2). In this case, \( \tau_\pm \) must be pseudoscalar, while \( \tau_0 \) scalar or vector.** This choice, which may also be adopted in the first model (1), excludes the process \( \tau_\pm \to 2\pi \) in favor of \( \tau_\pm \to \tau_0 + \pi \) and \( \tau_\pm \to 3\pi \) (Powell's case).\textsuperscript{5,10} There are the following nine couplings:

\[ V N \pi, \quad V N \tau_\pm, \quad V N \tau_0, \quad V V \pi, \quad V V \tau_\pm, \quad V V \tau_0, \quad N N \pi, \quad N N \tau_\pm, \quad N N \tau_0. \]

Of these, \( NN\pi \) is known, and \( NN\tau_\pm \) and \( V N \tau_0 \) turn out either unnecessary or harmful. Among many possible combinations of the remaining couplings few yield consistent results. Thus we take as a relatively reasonable choice (see Appendix):

\[ \begin{align*}
G_1^2 & \approx 10^{-2}, \quad G_2^2 \approx 10^{-1.5}, \quad G_3^2 \approx 10^{-6}, \\
V V \pi & \quad V N \pi \\
G_4^2 & \approx 10^{-1.5}, \quad G_5^2 \approx 10^{-15}, \quad \text{others}=0. \quad (6)
\end{align*} \]

These estimations are of course susceptible to fluctuations, by as large a factor as \( \sim 10^{\pm 2} \), depending on different assumptions on the calculational procedure.

At present we cannot tell with confidence which of the above two alternatives (1) and (2) is the more preferable. The former is relatively free from ambiguities and conflicts in determining the coupling constants. The idea of the existence of a series of excited levels of nucleons also attracts us. On the other hand, however, the latter cannot be excluded and even seems natural in view of the other evidences concerning \( \tau \) mesons, e.g. Powell's \( \tau_\pm \to 3\pi \) decay, which can well compete with \( \tau_\pm \to \tau_0 + \pi \) on this model. It is hoped that the forthcoming paper of Butler et al. will settle this question.

In conclusion, we should like to call attention to some effects which could be related to the \( V \) and \( \tau \) mesons. First, the nuclear force would be modified. But the range being at most only \( \sim 1/m_\pi \sim 2/m_\tau \), the effect would be too small to account for the existing \( N \bar{N} \) scattering data. Second, the conventional strong coupling theory, which allows the nucleon isobars of both charges to occur not as anti-particles, could be tested by the experiments, in which the stability of nuclei should also be taken account of. (According to our models, the anti-particles can only appear as pairs.)** Third, the new particles would play some part in the anomalous magnetic moment of nucleons, though we do not know how and to what extent. Fourth, the production of these particles, though depending on the model, would occur mainly a \( V-\tau \) pairs and \( V-V \) pairs, and to a lesser degree as single (or multiple) \( \tau \)'s. The corresponding threshold energy would be about 1.1 Bev (\( \tau + N \to V + \tau \)) and 0.8 Bev (\( N + N \to V + V \)) respectively in the laboratory system. So far these predictions are not definitely at variance with experiments.\textsuperscript{9}

A more detailed account of the present analysis will be given later.
Appendix

On the second model (Eq. (2)), the possible competing processes which need consideration are as follows

\[ \tau_0 \rightarrow 2\pi, \quad \tau_0 \rightarrow \pi_0 + \gamma, \quad \tau_0 \rightarrow 2\gamma; \]

\[ \tau_\pm \rightarrow \tau_0 + \pi_\pm, \quad \tau_\pm \rightarrow 3\pi, \quad \tau_\pm \rightarrow \pi_\pm + 2\gamma; \]

\[ V \rightarrow N + \pi. \]

From these processes we can first determine the relative magnitude of the coupling constants so as to fit the experimental facts, and then normalize them by some process such as the production rate. A crude life-time formula is, for example, furnished by

\[ 1/t \sim (G_i^2)(G_j^2)I_3/m_\pi \sim (G_i^2)(G_j^2) \times 10^{13} \text{sec}^{-1} \]

for \( \tau_0 \rightarrow 2\pi, \)

where \( I_3 \) means the available volume per unit energy of momentum space. An additional factor \( \sim 10^{-3}(\sim (m_\pi/m_V)^3) \) may be introduced if we take account of the coordinate space volume corresponding to the third order process in which virtual \( V \)-pairs are created (see Figure). This estimation also agrees roughly with the results of covariant calculation using regulators. The numerical values given in (6) were obtained by the latter refined method assuming scalar and pseudoscalar coupling for the scalar \( \tau_0 \) and pseudoscalar \( \tau_\pm \) respectively.

The first model (1) may be treated analogously.

*) Spin 3/2 for \( V \) would make the decay \( V \rightarrow N + \pi \) forbidden of first order if it were allowed for spin 1/2.

(**) Actually pseudovector \( \tau_\pm \) is to be discarded since they favor \( \tau_\pm \rightarrow \pi_\pm + \gamma \) (assuming \( \pi \) to be pseudoscalar) for \( \tau_0 \), either pure neutral scalar or symmetrical neutral vector must be taken in order to allow the process \( \tau_\pm \rightarrow \tau_0 + \pi_\pm \).

(***) For example, the process: \( -V_0 \rightarrow P_- + \pi_+ \) would be much rarer than \( V_0 \rightarrow P_- + \pi_+ \) in our case. This is consistent with experiments.

Feynman diagrams for decay and production on the second model (2).
Those on the first model are analogous.


5) Cloud chamber data:
   a) L. Leprince-Ringuet and M. L'heritier, C. R. 219 (1944), 616.
   b) R. Brode, Rev. Mod. Phys. 21 (1949), 37.
   Also see refs. 1), 2), 3) and 8).
   Photographic emulsion data:
   f) L. Leprince-Ringuet, Rev. Mod. Phys. 21 (1949), 42.
   g) H. H. Forster, Phys. Rev. 77 (1950), 733.
   h) N. Wagner and D. Cooper, Phys. Rev. 76 (1949), 449.
   Also ref. 4).

6) Neutral mesons:
   c) J. Steinberger, Phys. Rev. 76 (1949), 1180.
   r-mesons: