On the Nature of $V$-Particles, II

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July 31, 1951

In a preceding letter\(^1\) we have proposed two possible interpretations of the phenomena associated with $V$-particles, mainly on the basis of Butler et al.'s recent observations.\(^2\) Of course these interpretations have not been claimed to be the only and definite, but merely possible and more or less natural ones. Also the whole argumentation itself was not complete and exhaustive enough to get full insight into the nature of the $V$-particles. In view of these points, we will here supplement the previous letter with some more general considerations, while adding to our knowledge the experimental results of American groups\(^3\) in so far as they are accessible to us.

Of the various properties of the $V$-particles which are known to us, the most remarkable seems to be their large yield and long life, two apparently contradicting properties on the basis of simple detailed balance consideration. They suggest that production and decay are not inverse processes and/or some kind of selection rules (in a very general sense) are at work in the decay reaction. On the other hand, among what are not yet clarified experimentally, there are such important things as the identification of the decay products of the $V$-particles and their decay modes. Thus at least some of the decay mesons could be $\mu$-mesons (e.g. $\tau \rightarrow \pi + \mu$), and some of the decays could or should involve three or more product particles\(^4\) (e.g. $\tau + \pi_\sigma \rightarrow 2\pi_\pm \ V \rightarrow N + \mu + \nu$). Since no other crucial evidences are known (such as the mode of $V$ production), we are led to a wide variety of possible interpretations if we will take all these points into account, and they can be recommended or disfavored only after a closer examination.

Following the above considerations, let us
first summarize as follows the various conceivable assumptions which shall serve to find out and characterize systematically the possible individual models: 1) Assume the \( V \)-particles as elementary entities obeying some basic field equations; or 1) Regard them as composite substance with substructure. 2) Regard \( V \) and \( \tau \) as separate and independent events; or 2) Regard them as inherently related. 3) Assume the product mesons to be \( \pi \)'s only; or 3) They may involve \( \mu \)'s as well. 4) Assume only two-particle decays; or 4) Allow of three or more particle decays. 5) In order to account for the large difference in production and decay rate: a) Use the relation in mass values (e.g. for production, \( r+N\to V+\tau \), but for decay the inverse is forbidden energetically). b) Assume some unknown parents which, directly produced in nuclear events, decay instantly into the observed \( V \)'s (analogy of \( \pi \) and \( \mu \) mesons). c) Assume an interaction mechanism such that \( V \)'s are generated in a nucleon-nucleon impact, but are hard to decay singly (e.g. \( N+N\to V+V \)). d) Take advantage of large internal angular momenta for \( V \), which make the decay highly forbidden. e) Take advantage of parity and other selection rules related to transformation properties (including Furry's theorem). f) Other special devices. These various assumptions are not mutually exclusive, but may be appropriately combined. 6) Use the conventional perturbation theory (weak coupling); or 6) Exploit the strong interaction (like Fermi\(^{19}\)) or do not depend on the details of coupling at all (e.g. selection rules which can be enunciated by observing only the initial and final states).

By suitable combinations of these characteristic assumptions, we shall be able to arrive at a large number of models (or interpretations) which can explain more or less consistently the essential features of \( V \) events. We give below some of the representative models that follow in this way from our present general consideration, and make comments on their merits and defects.

1) All observed processes are assumed to be direct ones. For example, we introduce the following couplings:
   a) \( N\, N\, N\, V \, \tau, \, V\, N\, \pi, \, \tau\, \pi\, \pi \) \((12345c6)\).  
   b) \( N\, V'\, \tau, \, V'\, V\, \pi, \, V\, N\, \pi, \, \tau\, \pi\, \pi \) \((m_v, m_v, m_v)\) \((12345h6)\).  
   c) \( N\, N\, V, \, N\, N\, \pi, \, V\, N\, \pi, \, \tau\, \pi\, \pi \) \((12345c6)\).

This standpoint is equivalent to determining all the relevant terms of the \( S \)-matrix independently in so far as they do not lead to inconsistencies. Though formally possible, it is not a very attractive procedure since we little understand the nature of the events by such a highly phenomenological approach. The introduction of a short-lived parent \( V \)'s as in the above second model, seems to be an unnecessary complication unless some definite evidence on the existence of such a particle is presented.

2) Our two models proposed in I \((12345a6, b)\). They were specially designed to account for the successive decays of \( V \) or \( \tau \). But the pairwise production which they predict does not seem to be favored by experiments, if not yet rejected.

3) A three particle decay is assumed for \( V \): \( V\to N+\mu+\nu \), while the production occurs, for example, as \( V+\pi \) pairs \((12345a6)\). Since some evidences show that the decay does not necessarily follow a two-body scheme, such a possibility will not be excluded as responsible for at least part of the decays. (But a universal Fermi-type coupling \((\frac{g}{g\sim 10^{-4}})\) would lead to a rather long life \((>10^{-6}\) sec).)  

4) Gamow-type model. Turning to the structural theories, the most naive one may be to regard \( V \) as a bound \( N+\pi \) system \((12345cd6)\). This, however, would require an unusually high potential barrier (or the order of several Bev) to assure the long life, and if this barrier were supplied by the centrifugal force, the angular momentum would have to be \( \sim 8 \), which seems too high to be easily attained by nucleon-nucleon collisions.
(N+N→V+N).

5) We may modify the above model so that V is a bound N+τ system. The assumed interaction is, for example,

τπNN (for τ and V production), τππ (for τ and V decay) (I2845ac6),
or τNN (for τ and V production), τππ (for τ and V decay) (,,).

The decay of both V and τ are controlled by the same coupling τππ. The first model will predict the pairwise production, whereas on the second (τ must be a boson), the process V→N+τ is threatened by V→N+γ.

6) Isomeric transition. Alternatively we amend the defects of model 4 by assuming that in the decay of V the π meson is radiated from a small volume of the dimensions of nucleon Compton wave length (I2845cd16). Using the well-known multiple radiation formula, the angular momentum L can be lowered to ~4, which is not unreasonable to be realized by nuclear collisions. But in order to suppress the γ-emission, the bound meson field which is responsible for the excitation energy would have to be extremely rigid. If we calculate ad hoc the moment of inertia of the bound meson field around a nucleon and quantize this rigid body we obtain the observed excitation of ~200 Mev for L=4½ with the coupling constant \( g^2 \sim 10 \), and only the transitions to \( L=1/2 \) or \( 3/2 \) are energetically allowed for π emission. Although this model is interesting, it is hard to be founded upon orthodox field theory. The conventional strong coupling theory, on the other hand, which is similar to above in physical ideas, does not seem to give the required long life of the excited states.

Some remarks may be added on the spin (or transformation property) of V and τ particles. We did not take it into account in the above classification since it did not seem essential in the characterization of the models. In general both fermion and boson property may be allowed for these particles. But in any way the stability of protons and neutrons should be guaranteed. Thus, for instance, a coupling like \( VN\mu \) (V = boson elementary particle), leading to \( V→N+\mu \), cannot be admitted.

In this way we have seen that at the present stage several different model can assert themselves just about as good. But, in general, we may say that the elementary particle theories (Alternative I) are liable to predict pairwise production which remains to be confirmed by experiment, while the structural theories (Alternative I) tend to suffer from high probabilities of radiative decay. It will be premature and useless to demand anything more definite from what we know at present about the V particles.

In concluding, we express deep gratitude to Prof. S. Hayakawa for informing us of the recent activities of American groups as his own opinions. The models mentioned here include those which have been proposed in America, but no published papers being available, we have refrained from explicit citation.7) Thanks are also due to Messrs. G. Takeda, S. Takagi, H. Fukuda, K. Aizu, T. Kinoshita, H. Miyazawa and S. Oneda for valuable discussions.

References

1) Y. Nambu, K. Nishijima and Y. Yamaguchi, Prog. Theor. Phys. 6 (1951), this number. Cited in the text as I. The notations used here follow those of I.
2) C. C. Butler et al., Nature 167 (1951), 591. See I.
3) a) H. S. Bridge and M. Amnis, Phys. Rev. 82 (1951), 445.
c) W. B. Fretter, ibid. No. 5, p. 16.
f) E. J. Althaus, ibid.
5) This type of model was suggested by S. Takagi.
6) The first of these was also proposed by S. Oneda.
7) According to Prof. Hayakawa, theories have been given by R. P. Feynman, E. Fermi, R. E. Marshak, R. F. Christy and others.
* ) This notation signifies the nature of the model according to the above mentioned criteria.