Charge Independence for V–particles*

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Assuming the charge independence for V–particles, the qualitative features of these unstable heavy particles are investigated.

In view of the present experimental material, there seems to be three charge states for V_1:

(1) $V_1{}^\circ$: This particle has been most thoroughly investigated by many workers, and known to decay as $V_1{}^\circ \to p + \pi^- + Q$, $Q \sim 37$ Mev.

(2) $V_1{}^+$: This particle was discovered by the Pasadena group.[1] $V_1{}^+ \to p + \pi^\circ + Q$, $Q \sim 40$ Mev.

(3) $V_1{}^-$: One case was found in the cosmotron experiments[2] that seems to require the existence of $V_1{}^-$, although not conclusive. It is as yet not clear whether the isotopic spin of V_1 is 1/2 or 1 or higher. We shall, however, tentatively assign it as equal to 1, since this case is of special interest. Then from the cosmotron experiments,[3] $V_4{}^\circ$ or $V_2{}^\circ$ which is tentatively denoted as Π° should have a half integral isotopic spin[4] in reference to the process

$$\pi^- + p \to V_1{}^\circ + \Pi^\circ, \quad (\Pi^\circ \to \pi^+ + \pi^-). \tag{1}$$

If we assume that there is no doubly charged counter particle to Π°, the isotopic spin of Π should be 1/2. In such a case Π^+ and Π° are treated just as proton and neutron so long as we are concerned with their transformation properties in isotopic space. Hence the Π°–particle should be described by a complex wave function as well as the charged Π–particle, and we must distinguish between the Π°–particle and its anti-particle $\tilde{\Pi}^\circ$. This distinction leads to many interesting results as we shall see later.

From the above isotopic spin assignment we have the following results.

(1) The "even-odd" rule[5] is an inevitable consequence of the charge independence. If both the spin and isotopic spin of a hot particle* are integer or half-integer we call it an even particle, whereas if only one of them is integer and the other is half-integer we call it an odd particle. The even-odd rule holds for such an even-odd assignment of hot particles. Hence the large abundance and the striking stability of the V–particles against π– or γ–decay are automatically guaranteed. Recently Pais derived this rule from his own theory of the "ω"–space[6] by imposing the conservation of the ω–parity, while in the present work it is derived with less new elements.

(2) In production processes, we have the following conservation law valid for the charge independent and electromagnetic interactions

$$n(V_1) - n(\Pi) = \text{const.}, \tag{2}$$

where $n(V_1)$ is the no. of V_1–particles minus the no. of anti-V_1–particles and $n(\Pi)$ the no. of Π^+ and Π° minus the no. of $\tilde{\Pi}^-$ and $\tilde{\Pi}^\circ$. This law is proved as follows.

From the above isotopic spin assignment for V_1– and Π–particles, we have

$$q = I_3 + 1/2(n(N) + n(\Pi)), \tag{3}$$

where q and I_3 are the total charge and the third component of the isotopic spin of the system of hot particles.

There is another conservation law, the conservation of baryons**

$$b = n(V_1) + n(N) = \text{const.}. \tag{4}$$

Since q, b and I_3 are conserved for the charge independent and electro-magnetic interactions, we have from (3) and (4)

$$n(V_1) - n(\Pi) = b - 2(q - I_3) = \text{const.}.$$

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* After the completion of this work, the authors knew in a private letter from Prof. Nambu to Prof. Hayakawa that Dr. Gell-Mann has also developed a similar theory.

* By a "hot particle", we mean a particle with strong nuclear interaction.

** The "baryon" is the collective name for the members of the nucleon family. This name is due to Pais. See ref. (6).

Especially in pion-nucleus or nucleon-nucleus impacts, (2) can be written as

$$n(V_1)=n(\Pi)=n(\Pi^+,\ \Pi^0)-n(\tilde{\Pi}^-,\ \tilde{\Pi}^0). \qquad (5)$$

It must be noticed that in cases of heavy nuclei the Coulomb effects cannot be discarded and hence the validity of the conservation law for the electromagnetic interaction is necessary.

The conservation law (5) can forbid many processes, *e.g.*

$$\pi^-+p\rightarrow V_1{}^+ +\tilde{\Pi}^-, \qquad (6)$$

$$N+N\rightarrow V_1+V_1, \text{ etc. } (N\text{: nucleon}). \qquad (7)$$

Hence the production of V-particles in nucleon-nucleon collisions will be due to the processes such as

$$N+N\rightarrow N+V_1+\Pi, \qquad (8)$$

or

$$N+N\rightarrow N+N+\Pi+\tilde{\Pi}. \qquad (9)$$

(3) Since the process (7) is forbidden, we may conjecture that the production of V-particles will result mainly in pion-nucleon (or nucleus) collisions rather than in nucleon-nucleon (or nucleus) collisions at energies where the cosmic ray experiments are being performed, i.e. at about 10 Mev in the laboratory system and about 2 Mev in the centre of mass system, in conformity with the experimental viewpoint.[7]

(4) From the rarity of the σ-stars produced by negative heavy mesons the Bristol group[8] conjectured that the positive K-particles might be much more abundant than the negative ones.

Since the V_1-particles are supposed to be more easily produced than the Π- mesons because of the lower excitation energy to transform a nucleon into a V_1-particle than the energy required to create a heavy Π-meson, the production of V_1-particles in high energy nuclear events will occur in such a manner that $n(V_1)$ assumes as large a value as possible for a fixed value of $n(\Pi^+,\ \Pi^0)+n(\tilde{\Pi}^-,\ \tilde{\Pi}^0)+n(V_1)$. Then from eq. (5), we may expect

$$n(V_1)\sim n(\Pi^+,\ \Pi^0)\gg n(\tilde{\Pi}^-,\ \tilde{\Pi}^0). \qquad (10)$$

If we identify the K-particles with the Π-particles, then the conjecture of the Bristol group can be interpreted in terms of the relation (10). However, in the cloud chamber experiments both the positive and negative V-particles lighter than nucleon are observed comparably.[9] Thus it is an important problem to settle how many kinds of charged V-particles are present in nature.*

(5) The selection rules imposed by the charge conjugation and charge symmetry[10] cannot be applied to Π-meson decays. Since the real and imaginary parts of the complex wave function of Π^0 have opposite parities under charge conjugation, we cannot apply the selection rule

$$n(v)+n(t)=\text{odd is forbidden,} \qquad (11)$$

for transition among neutral Bosons, to Π^0.

For charged Π-particles the CT transformation[10] when applied to $\Pi^\pm$ alters its charge state, so that in this case, too, we cannot apply the second selection rule

$$n(v)+n(t)+n(\tau_3)=\text{odd is forbidden,} \qquad (12)$$

for non-radiative transitions, to $\Pi^\pm$.

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1) York, Leighton, and Bjornerud, Phys. Rev. **90** (1953), 167.
2) C. N. Yang's report on the cosmotron experiments. Lecture at the International Confererence on Theoretical Physics, held at Kyoto, Sept. 1953. Some V_1 decays seem to contradict the evenodd rule by exhibiting a cascade decay of a heavy unstable particle. See in this connection ref. (4) in which the generalization of the even-odd rule is discussed.
3) Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **91** (1953), 1287. See also ref. (2).
4) K. Nishijima, Prog. Theor. Phys. **9** (1953), 414. In this paper, it was stated that a Boson cannot assume a half-integral isotopic spin. However, there are special exceptional cases which are the matter of interest in the present work.
5) A. Pais, Phys. Rev. **86** (1952), 663.
6) A. Pais, Lecture at the International Conference on Theoretical Physics. Prog. Theor. Phys. **10** (1953), 457.
7) Leighton, Wanlass, and Anderson, Phys. Rev. **89** (1953), 148.
8) See for instance, Fowler, Menon, Powell, and Rochat, Phil. Mag. **42** (1951), 1040.
9) Astbury et al., Phil. Mag. **43** (1952), 1283. Astbury et al., ibid. **44** (1953), 242.
10) A. Pais and R. Jost, Phys. Rev. **87** (1952), 871.

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* If particles with different names correspond to the different modes of decay of an identical particle, the branching ratio of these modes should be constant independently of the mechanisms and energies of the production processes.