tion with another problem prevented a careful investigation and partly because experimental consequences seemed remote. Recently, however, Dr. Burton J. Moyer in a private conversation informed the author that an experimental search for the Nambu particle is quite feasible. If these superficial remarks serve to encourage such a search, they are perhaps justified.

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[1]W. R. Frazer and J. R. Fulco, Phys. Rev. Letters 2, 365 (1959).

[2]Geoffrey F. Chew, Robert Karplus, Stephen Gasiorowicz, and Fredrik Zachariasen, Phys. Rev. 110, 265 (1958).

[3]P. Federbush, M. L. Goldberger, and S. B. Treiman, Phys. Rev. 112, 642 (1958).

[4]Geoffrey F. Chew, University of California Radiation Laboratory Report UCRL-8194, February, 1958 (unpublished).

[5]It was pointed out to the author by Ben Mottelson that a three-pion state with $J=1$ and odd parity can be constructed which has only $l=1$ relative angular momentum for each pair.

[6]Yoichiro Nambu, Phys. Rev. 106, 1366 (1957).

[7]Presumably, the most important decay modes are $(3\pi)_B \to \pi^0 + \gamma$ and $(3\pi)_B \to \pi^+ + \pi^- + \gamma$, with rates $\sim 10^{20}$ sec^{-1}.

EFFECTS OF TWO ADDITIONAL PARTICLES ON THE SYMMETRIES IN STRONG INTERACTIONS*

D. B. Lichtenberg
Physics Department, Michigan State University, East Lansing, Michigan
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It is well known that, within the framework of the formula of Gell-Mann[1] and Nishijima[2] relating the strangeness of a particle to its baryon number, charge, and third component of its isotopic spin, there is room for additional particles. One of these, which we shall call D, following Yamanouchi,[3] is a positively charged meson with strangeness $S=2$ and isotopic spin $I=0$. Another, which we shall call Ω,[4] is a negatively charged baryon with $S=-3$ and $I=0$.[5] It is the purpose of this note to point out that if the D and Ω exist, the conclusions of a number of authors[6-9] about the symmetries of the strong interactions must be modified.

If we consider only meson-baryon interactions which are linear in the meson fields and bilinear in the baryon fields, the most general charge-independent interactions including the new particles are of the form

$$H_\pi = G_{\pi NN}\bar{N}\vec{\tau}\cdot\vec{\pi}N + G_{\pi\Lambda\Sigma}(\bar{\Lambda}\vec{\pi}\cdot\vec{\Sigma} + \text{H.c.}) + G_{\pi\Sigma\Sigma}\bar{\vec{\Sigma}}\cdot\vec{\pi}\times\vec{\Sigma} + G_{\pi\Xi\Xi}\bar{\Xi}\vec{\tau}\cdot\vec{\pi}\Xi,$$

$$H_K = G_{K\Lambda N}(\bar{N}K\Lambda + \text{H.c.}) + G_{K\Sigma N}(\bar{N}K\vec{\tau}\cdot\vec{\Sigma} + \text{H.c.}) + G_{K\Lambda\Xi}(\bar{\Xi}K_c\Lambda + \text{H.c.}) + G_{K\Sigma\Xi}(\bar{\Xi}K_c\vec{\tau}\cdot\vec{\Sigma} + \text{H.c.}) + G_{K\Xi\Omega}(\bar{\Xi}K\Omega + \text{H.c.}),$$

$$H_D = G_{DN\Xi}(\bar{N}D\Xi + \text{H.c.}) + G_{D\Lambda\Omega}(\bar{\Lambda}D\Omega + \text{H.c.}), \qquad (1)$$

where H.c. stands for Hermitian conjugate and we use the notation of Gell-Mann[7] that the symbol for a particle stands for the operator that annihilates it. Here K is a spinor and K_C the charge conjugate spinor, and they are given by

$$K = \begin{pmatrix} K^+ \\ K^0 \end{pmatrix}, \quad K_C = \begin{pmatrix} \bar{K}^0 \\ -K^- \end{pmatrix}.$$

In (1) we have emphasized the form of the interaction in isotopic spin space. If the π, K, and D are all pseudoscalar mesons, and all the baryons have the same spin and parity, then all the interactions in (1) will contain an additional factor which will be either γ_5 (pseudoscalar coupling) or $\gamma_5\gamma_\mu\partial/\partial x_\mu$ (pseudovector coupling).

In the absence of further symmetries, there are eleven coupling constants to be determined before the interactions are specified. However, we can postulate that all pion-baryon coupling constants are equal (global symmetry), all K-baryon couplings are equal (cosmic symmetry), and all D-baryon couplings are equal (which we might as well call galactic symmetry). Then the number of independent coupling constants is reduced to three: G_π, G_K, and G_D. (If the interactions are pseudovector, we can speculate that there is only one dimensionless coupling constant, i.e., $M_\pi G_\pi = M_K G_K = M_D G_D$, where the M's are the meson masses. The constants $M_\pi G_\pi$ and $M_K G_K$ appear to be approximately equal experimentally.)

One of the reasons for postulating the existence of the D and Ω is as follows: Pais has shown that, provided the commonly assumed baryon mass spectrum is complete, global and cosmic symmetry cannot hold simultaneously without contradicting experiment.[10] For example, the reaction

$$\pi^+ + p \to K^+ + \Sigma^+ \qquad (2)$$

would be forbidden to order Δ^2, where $\Delta = (M_\Sigma - M_\Lambda)/M_\Lambda$, relative to the reaction

$$\pi^- + p \to K^+ + \Sigma^-. \qquad (3)$$

However, both reactions are seen experimentally with comparable cross sections. The existence of either the D or Ω without the other would not be enough to break the selection rule which forbids (2), but if both exist, the reaction is allowed. All the other discrepancies with experiment pointed out by Pais also disappear if D and Ω are both present.

A second reason for postulating the existence of the two new particles concerns the baryon mass spectrum. If the baryons all have the same bare mass, then this mass degeneracy is not removed within the framework of the commonly assumed particles, provided global and cosmic symmetry both hold and the only strong interactions are of the form (1). The existence of either new particle would partially lift the degeneracy, but only if both are present do the baryons (including Ω) split into five distinct levels. We have not attempted to determine whether this splitting is in the right direction to give the observed ordering of the masses of the baryons.

These statements about cross sections and mass degeneracies follow from the form of the interactions given in Eq. (1) even when global, cosmic, and galactic symmetries hold simultaneously. This can be seen by noting that the Ω is distinguished from the other baryons at the outset by having no π interactions. Then the Ξ is distinguished from the others by being the only baryon coupled to the Ω via K interactions. The nucleon becomes split from the Λ and Σ at this stage through indirect effects. However, the Λ and Σ remain degenerate, and Pais' rules still hold, since the Λ and Σ can still be written as two charge doublets instead of as a singlet and triplet without altering the form of the interactions (see references 7 and 8). Turning on the D interaction further distinguishes the nucleon, since it is the only baryon coupled to the Ξ by the D. At the same time, the Λ is distinguished from the Σ, since the Λ is coupled to the Ω via the D, whereas in a charge-independent interaction of the form assumed, the D, Ω, and Σ cannot be coupled.

Alternatively, the proof may be given by the use of perturbation theory. We need consider only second and fourth order diagrams and note that the graphs in which D and Ω appear remove mass degeneracies and destroy the relations that were deduced by Pais.

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[2]K. Nishijima, Progr. Theoret. Phys. (Kyoto) 10, 581 (1953).

[3]T. Yamanouchi, Phys. Rev. Letters 3, 480 (1959). The experimental evidence cited by Yamanouchi for the D is inconclusive, as he himself points out.

[4]Y. Eisenberg, Phys. Rev. 96, 541 (1954), has reported a cosmic-ray event which might be interpreted as evidence for the Ω.

[5]Excluding multiply charged particles, there is also room for a neutral meson with $I = 0$ and $S = 0$ (the $\pi_0{}^0$), and for baryons with $S > 0$. We do not consider these possible particles here.

[6]J. Schwinger, Phys. Rev. 104, 1164 (1956); Ann. Phys. 2, 407 (1957).

[7]M. Gell-Mann, Phys. Rev. 106, 1296 (1957).

[8]A. Pais, Phys. Rev. 110, 574 (1958); 110, 1480 (1958).

[9]J. J. Sakurai, Phys. Rev. 113, 1679 (1959); 115, 1304 (1959).

[10]Pais actually assumed weaker conditions (see reference 8).