A NINTH BARYON?*

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This note reports some results obtained by elementary calculations from a new field theory of matter. The theory is an attempt to explore the otherwise inaccessible substratum of the nuclear world with the aid of an analogy between nucleonic charge N and electrical charge Q. Fundamental fields and physical particles are presumed to be in direct correspondence for the leptons. The multiplicity of the leptonic component ($N=0$) of the fundamental Fermi field ψ is 2×3, representing the particles $\mu^{\pm}$, $e^{\pm}$, ν, $\bar{\nu}$. The dynamics of the leptonic world is described by the vector electromagnetic field A which is coupled to the exactly conserved charge Q, and by the vector field Z which interacts with exchanges of electrical charge and is responsible for the phenomenological weak interactions.[1]

A symmetry in N and Q multiplicities is obtained if the nucleonic component ($N=\pm1$) of the primitive Fermi field is also assigned the multiplicity 2×3, with $Q=0$ represented twice and $|Q|=1$ occurring once, for each N. As a provisional assumption, $Q=\mp1$ is ascribed to $N=\pm1$. Nucleonic charge is defined dynamically by the vector field B, which is coupled very strongly to the exactly conserved charge N since a particle analogous to the photon does not exist.[2] The qualitative analogy is completed by introducing a vector field that interacts with exchanges of nucleonic charge. In order to confine such exchanges to the nonleptonic world, this Bose field is assigned two units of nucleonic charge. It is assumed that the electric charge structure of $V(N=\pm2)$ duplicates that of $\psi(N=\pm1)$. There are three components, one with $Q=\mp1$ and two with $Q=0$.

A simplified picture of the nucleonic world appears if ψ and V are coupled to B, in accordance with their nucleonic charges, but not to each other. The symmetry of this physically degenerate situation is described by two independent internal U_3 transformation groups which are associated with respective nucleonic charge bearing fields. (The symbol W_3 may be suitable for this underlying internal symmetry group.) With the conditions of strong binding between oppositely charged fields that are necessary for the suppression of a massless particle associated with the B field, one anticipates the existence of low-lying physical excitations. There are boson excitations with $N=0$, and fermion excitations with $N=\pm1$. These are identified with degenerate families of mesons having spin-parity $0^{\pm}, 1^{\pm}, \cdots$, and with families of baryons having spin-parity $\frac{1}{2}^{\pm}, \frac{3}{2}^{\pm}, \cdots$. The meson states generated by the operator products $\bar{\psi}_a\psi_b$ and $\bar{V}_aV_b$ constitute two independent sets of unitary octuplets, together with unitary singlets. The baryon states generated by $\bar{\psi}_aV_b$, and their adjoints $\bar{V}_a\psi_b$, form nonuplets since the two unitary groups are independent.

The interaction between ψ and V must be constructed from the nucleonic charge-conserving terms $\psi_a\psi_b\bar{V}_c$ and $\bar{\psi}_a\bar{\psi}_bV_c$. But no linear combination of these forms can be invariant under common U_3 transformations of ψ and V. The dynamical mechanism for the breakdown of unitary symmetry is thus identified. The violation of U_3 symmetry is minimized by forming scalar products between $\bar{V}$ and a ψ, or V and a $\bar{\psi}$. This leaves a preferred axis in the three-dimensional unitary space, $a=3$, which must be associated with an electrically neutral component of ψ. The remaining U_2 symmetry is described in the conventional way by hypercharge and isotopic spin conservation. There is still a choice to be made, between a symmetrical and an antisymmetrical combination of $\psi_a\psi_b$, before forming a scalar product with $\bar{V}_b$ and setting $a=3$. If the antisymmetrical combination is used, V_3 and $\bar{V}_3$ will not appear in the coupling term. Such a theory is invariant under independent phase transformations of the field V_3, which is the assertion of another conservation law on the same dynamical level as hypercharge and isotopic spin conservation. Lacking evidence for an additional selection rule, that possibility is rejected and the symmetrical combination adopted. This choice also fixes the ψ-V coupling term to be pseudovector in structure.

Simple perturbation calculations have been performed in order to estimate the effect of the symmetry-destroying coupling between ψ and V. The latter is first effective in the second order. When applied to the nine degenerate baryon states, the perturbation produces the physical particles N, Ξ, Λ, Σ, and a ninth particle Y^0, with $Y=T=0$. If we add a condition of stability for N with respect to displacements of Y^0, the masses of the particles are found to be related by

$$\tfrac{1}{2}(N+\Xi)=\tfrac{1}{4}(3\Lambda+\Sigma) \tag{1}$$

and

$$Y^0=3\Sigma-2\Lambda. \tag{2}$$

The former is the well-known Gell-Mann–Okubo relation, previously derived from a description of the baryons as a unitary octuplet.[3] The empirical difference between the right- and the left-hand sides is 6 MeV. The mass predicted for the ninth baryon is

$$Y^0\simeq 1350 \text{ MeV}. \tag{3}$$

Is there a known particle with $Y=T=0$ in the neighborhood of this mass? The obvious candidate is Y_0^* at 1405 MeV. With this identification the latter is a particle of the same spin and parity, $\frac{1}{2}^+$, as the eight other baryons. This provides a crucial experimental test of these ideas. In other classifications[4] the particle has been assigned quantum numbers $\frac{1}{2}^-$ or $\frac{3}{2}^+$. Should ~55 MeV seem a disconcertingly large discrepancy, it may be comforting to know that higher order perturbation effects of the magnitude suggested by the 6-MeV imbalance in the mass formula (1) can suffice to produce the needed Y_0^* displacement. The stability condition for N implies a great sensitivity for Y_0^*.

The 1^- and 0^- mesons have been treated with the aid of a dynamical simplification that relates octuplet and singlet states directly to the nine states generated by $\bar{\psi}_a\psi_b$, despite the inclusion of a mass displacement between singlet and octuplet. The result of the perturbation calculation is a (mass)^2 relation which, for the 1^- particles, is

$$(\varphi-\rho)(\omega-\rho)=\tfrac{4}{3}(K^*-\rho)(\varphi+\omega-2K^*). \tag{4}$$

This equation is satisfied within experimental error. Since the errors of left- and right-hand side are dominated by that of ρ, the mass relation is most effectively used to predict ρ from the other masses, with the result

$$\rho^{1/2}=752\pm 5 \text{ MeV}. \tag{5}$$

The observed value is 755 ± 5 MeV.

The similarity of the states for the two types of mesons implies a relation between 0^- and 1^- masses given by

$$K-\pi=K^*-\rho. \tag{6}$$

The empirical[5] ratio of left- and right-hand sides is 1.036 ± 0.04. If the unknown ninth 0^- meson is called δ, the (mass)^2 relation

$$(\delta-\pi)(\eta-\pi)=\tfrac{4}{3}(K-\pi)(\delta+\eta-2K) \tag{7}$$

yields

$$\delta^{1/2}\sim 1.5 \text{ BeV}, \tag{8}$$

which should not be regarded as more than a qualitative prediction.

One can associate secondary, phenomenological fields with the particles and devise first approximations to the various couplings by the requirement of W_3 invariance. Thus, the pion coupling between Y_0^* and Σ is related to the pion-nucleon coupling, from which one derives the single-pion emission contribution to the width of Y_0^*,

$$\Gamma_\pi(Y_0^*)=\tfrac{4}{3}(f_{\pi N}^2/4\pi)(p^3/\mu^2)_\pi\sim 30 \text{ MeV}, \tag{9}$$

using $f_{\pi N}^2/4\pi=0.1$. The experimental width[6] is ~50 MeV. Another feature of the baryon-0^- meson interaction is the absence of $\bar{N}K\Sigma$ coupling, in this approximation. However, the relation between Λ and Σ couplings should be sensitive to the effect of the symmetry-destroying interaction, particularly if it is amplified by the small pion mass.

The baryon-1^- meson interaction asserts that φ is effectively not coupled to the nucleon. This is consistent with the marked weakness of φ production in πN collisions.[7] An interaction between the two types of mesons connects, through a single coupling constant, the reciprocal lifetimes for the three decays $\rho\to\pi+\pi$, $K^*\to K+\pi$, $\varphi\to K+\bar{K}$. From the known ρ width one predicts[8] (in MeV)

$$\Gamma(K^*)=35\pm 3,\quad \Gamma(\varphi)=2.4\pm 0.2. \tag{10}$$

The latter, in particular, agrees with the measured total width[9] 3.1 ± 1.0 MeV, in view of the small branching ratio[10] $(\varphi\to\rho+\pi)/(\varphi\to K+\bar{K})$ $=0.35\pm 0.2$. This suppression of the decay process $\varphi\to\rho+\pi$ is also a consequence of the theory, as the essential absence of $\varphi N\bar{N}$ coupling already indicates.

The details of these calculations together with applications to electromagnetic properties and weak interaction effects will be given elsewhere.

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[1]This part of the theory has already been described. J. Schwinger, Ann. Phys. (N.Y.) **2**, 407 (1957). The

only modification required is the interchange of the tentatively assigned polarization labels L and R to accord with later experimental results.

[2]J. Schwinger, Phys. Rev. 125, 397 (1962); 128, 2425 (1962).

[3]M. Gell-Mann, Phys. Rev. 125, 1067 (1962); S. Okubo, Progr. Theoret. Phys. (Kyoto) 27, 949 (1962); Y. Ne'eman, Nucl. Phys. 26, 222 (1961).

[4]S. L. Glashow and A. H. Rosenfeld, Phys. Rev. Letters 10, 192 (1963); R. E. Behrends and L. F. Landovitz, Phys. Rev. Letters 11, 296 (1963).

[5]This property of the mass data has been noticed by S. Coleman and S. L. Glashow (to be published). I have had the benefit of conversations with these authors.

[6]See, for example, C. Baltay et al., Phys. Rev. Letters 11, 346 (1963).

[7]Y. Y. Lee, W. D. C. Moebs, Jr., B. P. Roe, D. Sinclair, and J. C. Vander Velde, Phys. Rev. Letters 11, 508 (1963).

[8]Compare J. J. Sakurai, Phys. Rev. 132, 434 (1963).

[9]N. Gelfand et al., Phys. Rev. Letters 11, 438 (1963).

[10]P. L. Connolly et al., Phys. Rev. Letters 10, 371 (1963).

ERRATUM

GIANT QUANTUM OSCILLATIONS OF THE ATTENUATION OF TRANSVERSE ACOUSTIC WAVES IN A LONGITUDINAL MAGNETIC FIELD IN METALS. D. N. Langenberg, John J. Quinn, and Sergio Rodriguez [Phys. Rev. Letters 12, 104 (1964)].

In Eq. (6) v_0 should appear raised to the third power. The last inequality in reference 9 should read $\omega\tau > 1$. The second equation in reference 8, defining the function $\Phi_r(x)$, should read

$$\Phi_r(x) = \frac{-i\pi kT}{\hbar\omega_0}\,\frac{\exp(2\pi i r x/\hbar\omega_0)}{\sinh(2\pi^2 r k T/\hbar\omega_0)}.$$