

SYMMETRIC COMPOSITE MODEL OF STRONGLY INTERACTING ELEMENTARY PARTICLES

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A scheme is considered in which all baryons (p , n , Λ , Σ , Ξ) are composed of two particles and one antiparticle from a set of three elementary fermions A , B , C . It is shown that the best choice is that in which, as far as charge and strangeness are concerned, A and B are identical to Ξ^0 and Ξ^- and C is identical with Λ . The masses of A , B , and C are assumed to be large so that these particles are unstable with respect to strong interactions and are therefore unobservable. In this scheme the parity of all observable baryons is the same and opposite to the parity of the elementary fermions A , B , and C . Pions and K mesons are pseudoscalar with respect to the baryons.

FERMI and Yang¹ were the first to represent the π meson as being composed of a nucleon and an antinucleon.* The discovery of the strange particles led to a model in which there are three elementary fermions; Markov,³ Sakata,⁴ and Okun^{5,6} (collectively abbreviated SOM) developed such a model and outlined its consequences.

The elementary particles in the SOM scheme are p , n , Λ and their antiparticles \bar{p} , \bar{n} , $\bar{\Lambda}$; the mesons and the remaining hyperons are represented as composites, e.g., $\pi^+ = p\bar{n}$, $K^+ = p\bar{\Lambda}$, $\Sigma^+ = p\bar{n}\Lambda$, $\Xi^- = \bar{p}\Lambda\Lambda$, etc. Thus there exists a sharp distinction between the three "elementary" baryons and the five "composite" ones (3Σ and 2Ξ); on the other hand, the properties of the baryons, and in particular, their masses, give no justification for such a demarkation.

A number of authors⁷⁻⁹ emphasize that all eight known baryons are similar to one another in first approximation. There is thus a natural need for a scheme in which this similarity and the internal symmetry are recognized from the beginning. One such scheme, in particular, was proposed by Gell-Mann during a discussion at the Conference on the Physics of High Energy Particles at Kiev, 1959.

Let us consider the problem in its most general form. For this purpose we introduce three elementary fermions A , B , and C , which do not coincide with any of the known particles. We shall represent all known baryons as different composites of two particles and one antiparticle; the mesons will be composites of a particle and an antiparticle. Thus all three particles will be

assigned the baryon number (nucleon charge) + 1. We assume further that the strangeness of one particle (C) differs by one unit from the strangeness of the two other particles (A and B); A and B form an isotopic doublet, so that the charge of B differs from that of A by one unit. The masses of the particles A and B forming an isotopic multiplet are equal and their interaction with the third particle (C) is also the same. In such a scheme we have 3×3 different mesons and 18 different baryons.

The conclusions with respect to the mesons are identical to those made by Matumoto¹⁰ and Okun.^{5,6} Orthogonalizing the states with account of isotopic invariance, we divide the number of mesons into one triplet with $S = 0$, two doublets with $S = \pm 1$, and two singlets with $S = 0$ (S is the strangeness).

Evidently, the triplet $A\bar{B}$, $(A\bar{A} - B\bar{B})/\sqrt{2}$, $B\bar{A}$ represents the π mesons and the two doublets $A\bar{C}$, $B\bar{C}$ and $C\bar{A}$, $C\bar{B}$ represent the K and \bar{K} mesons.

The two singlets form linear combinations with unknown coefficients $\alpha\xi + \beta\zeta$ and $-\beta\xi + \alpha\zeta$, where $\xi = (A\bar{A} + B\bar{B})/\sqrt{2}$ and $\zeta = C\bar{C}$, $|\alpha|^2 + |\beta|^2 = 1$. These singlets describe hypothetical mesons of the type π_0^0 (or ρ_0), which are the subject of much criticism in the literature.^{5,10-12} According to our scheme there should be two of these mesons. However, if their masses are larger than $3m_\pi$ these mesons cannot be experimentally observed as particles.

As was shown by Fermi and Yang,¹ it must be assumed that particle and antiparticle are joined in an 1S state, i.e., with antiparallel spins; then pions and K mesons are pseudoscalar particles, because the product of the intrinsic parities of a fermion and an antifermion is identically equal to -1 .

*Consequences of the Fermi-Yang model concerning the mass difference between π^+ and π^0 and the β decay $\pi^+ \rightarrow \pi^0$ were considered by the author in reference 2.

Let us now turn to the baryons. We have, in a classification according to change of strangeness,

- 1) one doublet $CC\bar{A}$ and $CC\bar{B}$;
- 2) one triplet CAB , $C(A\bar{A} - B\bar{B})/\sqrt{2}$, CBA and two singlets consisting of linear combinations of $CC\bar{C}$ and $(A\bar{A} + B\bar{B})/\sqrt{2}$;
- 3) a quadruplet AAB , $A(A\bar{A} - B\bar{B})/\sqrt{2}$, $B(A\bar{A} - B\bar{B})/\sqrt{2}$, $BB\bar{A}$ and two doublets consisting of linear combinations of ACC , BCC and $A(A\bar{A} + B\bar{B})/\sqrt{2}$, $B(A\bar{A} + B\bar{B})/\sqrt{2}$;
- 4) one triplet AAC , ABC , $BB\bar{C}$.

It is natural to identify the doublet 1) with the nucleons, the triplet 2) with Σ , one of the singlets 2) with Λ and one of the doublets 3) with Ξ . For this identification we must assume that according to the existing classification A and B have the strangeness $S = -2$, while A is neutral and B has the charge $Q = -e$; C has the strangeness $S = -1$ and is neutral. Thus the conserved quantum numbers (charge, strangeness, baryon number) are the same for the pairs A and Ξ^0 , B and Ξ^- , and C and Λ , respectively.

Besides the known baryons, the scheme gives also a number of unobserved particles: a particle U of the Λ type ($Q = 0$, $S = -1$), a doublet V of the Ξ type ($Q = 0, -1$ and $S = -2$), a quadruplet W with $Q = 1, 0, -1, -2$ and $S = -2$, and a triplet R with $Q = 0, -1, -2$ and $S = -3$. The absence of these particles with $S = -1$ and $S = -2$ in experiment can be explained by assuming that they have large masses: $m_U > m_\Sigma + m_\pi$ (for $S = -1$); $m_V, m_W > m_\Xi + m_\pi$ for $S = -2$; then they are unstable against strong decay.

The fact that the particles R with $S = -3$ are not observed can be explained in an analogous way if their mass $m_R > m_\Xi + m_K$. It is possible, however, that these particles exist and will be discovered; the threshold for the production of R with the simultaneous production of $3K$ is extremely high and the probability for observing R is small.

The condition of Gell-Mann and Rosenfeld¹³ according to which the charge of the elementary particles must not be larger than unity is artificial and does not follow from the general ideas of the theory of isotopic invariance and strangeness. Therefore, the appearance of the doubly charged W and R particles is not a deficiency of the scheme.*

In principle, another variant of the scheme (Gell-Mann, Kiev) is possible, in which the

*We note that the known " ${}^{3/2}, {}^{3/2}$ " resonance in the scattering of pions from nucleons corresponds to an unstable state of the nucleons which includes the doubly charged state ($\pi^+ + p$).

quantum numbers of the pairs A and p, B and n, and C and Λ , respectively, coincide. In this variant the physical nucleons are identified with one of the doublets 3) and the cascade hyperons Ξ^- and Ξ^0 are described by the doublet 1). The triplet 4) has strangeness + 1.

We know from experiment that the mass increases as we decrease the strangeness, i.e., as we go from the nucleons ($S = 0$) to the cascade hyperons ($S = -2$). Thus one could easily imagine that the particles with $S = -3$ either do not exist or have not yet been observed. But it is difficult to understand why the particles with $S = +1$ have not been observed if they appear in the scheme. For this reason the first scheme ($A \equiv \Xi^0$, $B \equiv \Xi^-$, $C \equiv \Lambda$) appear to be closer to reality than the second ($A \equiv p$, $B \equiv n$, $C \equiv \Lambda$). There is no basis whatsoever for the pseudo-philosophical assertion, which one sometimes encounters, of the indistinguishability of the results of the different schemes.

Let us turn now to the problem of the relative position of the particles in the composite scheme. We must, evidently, assume mutual attraction between particle and antiparticle (and repulsion between two particles). Hence all particles are in S states with respect to the antiparticles. The spatial parity of all composite particles, i.e., of all physical baryons, is odd in the reference system in which the parity of the unobserved elementary particles A, B, and C is even (we assume that the parity of the antiparticles is odd). Since the parity of all physical baryons is the same, the pion and the K meson are pseudo-scalars in the reference system in which the parity of, e.g., p, n, and Λ is assumed to be even; in this reference system the parity of Σ and Ξ is also even, while the parity of A, B, and C is odd.

We note that in the SOM scheme, in which Σ and Ξ consist of p, n, and Λ , we would be led to an odd parity for Σ and Ξ , where the parity of p, n, and Λ is even. Although this conclusion is not conclusively refuted by experiment, it nevertheless seems to be highly improbable.

It would be especially desirable to carry out a direct measurement of the relative parity of Σ^0 and Λ by observing the polarization of the quanta in the decay $\Sigma^0 = \Lambda + \gamma$, as proposed by Feldman and Fulton.¹⁴

Since the particles repel each other, it is natural to assume that two particles are in an odd state relative to one another. This does not prevent them from being both in an S state with respect to an antiparticle. For example, for the system ABC we write

$$\psi = \varphi(r_{A\bar{C}})\chi(r_{B\bar{C}}) - \chi(r_{A\bar{C}})\varphi(r_{B\bar{C}}),$$

where φ and χ are two different (but both spherically symmetric) functions. This wave function is odd under the interchange of A and B, i.e., if we change the sign of r_{AB} . We can rewrite ψ in the form

$$\psi = \sum_i u_i(r_{AB})v_i\left(\frac{1}{2}(r_A + r_B) - r_C\right),$$

both functions u_i and v_i are odd, the overall parity of ψ does not depend on the way in which it is written and is odd if the intrinsic parity of the antiparticles is taken into account, as was already noted earlier.

The relative orientation of the spins is determined by the condition that the spins of particle and antiparticle are antiparallel; that this orientation is favored energetically follows from the fact that it is realized in the case of the mesons. For a baryon, which consists of one antiparticle and two particles, we then obtain the total spin $\frac{1}{2}$, as we should, while the spin wave function is even under the interchange of the two particles. In all, taking both the spin and space parts into account, the wave function changes sign under the interchange of the two particles. This is a characteristic feature of the whole scheme: owing to this antisymmetry, the Pauli principle does not forbid systems with two identical particles, as, for example, $CC\bar{A}$ or $A\bar{A}\bar{B}$.

If we assumed that the spatial function is symmetric under the interchange of the two particles, while the spin function retains its old properties, all systems with two identical particles would be excluded, and we would obtain 9 systems, which fall into three groups according to strangeness: $4 + 4 + 1$. It is not possible to fit the 8 known baryons, which fall into the three strangeness groups $2 + 4 + 2$, into such a scheme.

Finally, the variant with symmetric space and antisymmetric spin functions with respect to the interchange of the two particles is equivalent to our proposed variant as far as spin, parity, and the Pauli principle are concerned; but it is less favored energetically for two reasons: the repulsion of the particles and the spin dependence of the attraction between particle and antiparticle.

In the composite model it is assumed that approximate expressions for the masses of the composite particles can be given in the form of sums of the masses of the component elementary particles and terms depending on the pairwise interaction of the elementary particles. In conformity with our assumptions about the wave function, we shall consider only the negative contribu-

tion to the mass from the attraction between particle and antiparticle; thus in contrast to Matumoto,¹⁰ we shall not make use of the positive contribution from the repulsion of the two particles. Also, we shall not use the same interaction constant for the particle-antiparticle pair in baryons and mesons, since the wave functions are clearly different in the two cases. Thus seven constants enter into the formula for the mass of the baryons: $m_A = m_B = m$, $m_C = \mu$, the contribution from the interaction $A\bar{C}$ or $B\bar{C}$ equal to $-h$, and four quantities which characterize the interaction and the charge exchange of the three pairs $A\bar{A}$, $B\bar{B}$, and $C\bar{C}$, expressed in matrix form (in this form we taken into account that A and B form a doublet):

	$A\bar{A}$	$B\bar{B}$	$C\bar{C}$
$A\bar{A}$	k	l	m
$B\bar{B}$	l	k	m
$C\bar{C}$	m	m	n

In view of the isotopic invariance the interaction of the pairs $A\bar{B}$ and $B\bar{A}$ must be the same as the interaction of the neutral term of the isotopic triplet $(A\bar{A} - B\bar{B})/\sqrt{2}$, i.e., it is characterized by the quantity $k - l$.

Since the number of known different masses is four (the electromagnetic mass differences within the multiplets are neglected), there is sufficient freedom in the set of seven numbers to allow us to satisfy the inequalities necessary to explain non-observability of the elementary particles A, B, and C of the scheme themselves as well as of the supernumerary particles U, V, and W; the mass of R can be either larger or smaller than the sum $m_{\Xi} + m_{\Sigma}$, so that the formula for the mass does not permit us to draw a definite conclusion about the existence of R.

The main problem to be investigated is that of the role of the unobserved particles as possible excited states and wide resonances, i.e., the problem of how these particles show up in the dispersion relations for processes involving particles which are stable against strong decay. We note that the known " $3/2, 3/2$ " resonance should not be regarded as an unstable particle of our scheme, since in this scheme the spin of all particles — stable and unstable alike — is equal to $\frac{1}{2}$.

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