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The Fifth Interaction: Origins of the Mass Breaking Asymmetry*

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The relative success of the SU_3 mass formula, and the relevant choice of an asymmetric solution by spontaneous breakdown and bootstrap equations are explained by the suggestion of an additional interaction, similar to electromagnetism but some ten times stronger, mediated by a vector meson coupled to the strangeness $S=Y-B$ current. The possibility that this interaction may also be responsible for the muon mass is investigated.

THE CASE FOR THE FIFTH INTERACTION

THE success of the first-order mass formula[1,2] of[2,3] SU_3 has generally been received with mixed feelings. It is encouraging to find a symmetry producing such simple straightforward results—but it is also puzzling that what seems to be a first-order perturbation term, in the context of quantum field theory, should be experimentally exact even though it emerges via g_{strong}.

A bootstrap analysis, coupled with the symmetry formalism,[4] sheds some light upon the dynamical propagation of the mass breaking effect.[5,6] On the other hand, the bootstrapped system still has the choice between a fully symmetric solution and an asymmetric one. Once a perturbation is introduced, a self-consistent mass-breaking solution is allowed to exist—but one wonders what makes the equations vote for a nonsymmetric solution at all, and in the F_8 (or hypercharge) direction in particular. The only known "external" perturbation is provided by electromagnetism, and one would have expected the symmetry to break into U-spin multiplets[7]—that SU_2 subgroup of SU_3 which commutes with electric charge $Q=(\sqrt{3}F_3+F_8)/2$. Somehow, we have learned to compute the mass spectrum of the hadrons—without really understanding its origin. In a way, this is the beauty of the symmetry shortcut. Dynamically, it is unsatisfactory.

We would like to suggest a way out of this dilemma. Suppose there were just one more "type" of interaction, between the strong and the electromagnetic. The mass spectrum has always been assumed to derive from some graduation of very-strong and less-strong interactions, but what we now suggest is that this missing fifth is of a different nature than the strong interactions. It cannot be bootstrapped—just as one does not conceive at present a positron-electron pair to couple into a photon—they can only make positronium. This, of course, may be a temporary limitation—but it is just what is intended; if ever the "S-matrix approach" can cover all interactions, it will have evolved ways of breaking symmetries too. In the present context, we postulate a vector field, or particle, χ, with a coupling midway between the strong and electromagnetic interactions,

$$g_\chi^2/4\pi\sim 0.1-0.3$$

allowing us to use perturbation theory and believe in first-order terms (in g^2) as representing the main contribution to self-masses. [S^2 may contribute in part to the 27, but if the dynamical coefficient is small, the c and d of the general formula

$$\Delta M=a+bY+cY^2+dI(I+1)$$

will take on their first-order values $c=-d/4$ just as in the experimental situation for the decuplet masses.] This particle is coupled to the *strangeness* current,

$$S=F_8-B\,,$$

which will give the right rise of mass with increasing S^2 in a general way, conserve I and Y, and require all masses to obey the mass formula because it breaks the symmetry in the proper direction. Since its squared coupling is about 10–30 times larger than the photon's, it creates mass splits that are some 10–30 times larger than the electromagnetic mass splittings.

Does the χ have mass? If it is massless, it should be observed in radiative K-nucleon scattering, in ϕ, η decays, and perhaps in some χ-magnetic transitions in nuclei (as nucleons have no strangeness) and hyperfragments. It seems that most of these effects would be difficult to observe, and could have been easily confused with other neutral decay modes of emissions. Lee and Yang's[8] gravitational criterion wouldn't appear here as the earth is not strange.

On the other hand, χ may well be massive—as it could then also explain the muon's mass. This would entail assigning lepton-strangeness S_L to the muon, with $S=S_Y+S_L$. As its neutrino is not allowed to have a sizable mass, we would then think of π and μ decays

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as $|\Delta S_L|=1$ transitions, included in the weak interactions. On the other hand, μ would be coupled to the χ and participate directly in the fifth interaction. As to muon conservation, we would replace it by the Konopinsky-Mahmoud assignment[9] and a four-component neutrino where chirality conservation sets the count right with respect to the two neutrinos.[10] In the representation space

$$\begin{bmatrix}\mu^+\\ \nu\\ e^-\end{bmatrix}$$

the strangeness operator is

$$S_L=\begin{bmatrix}1 & \cdot & \cdot\\ \cdot & \cdot & \cdot\\ \cdot & \cdot & \cdot\end{bmatrix}.$$

The mass of χ would then have to be above the present lower bound as derived from the $(g-2)$ experiment.[11]

Computing the fifth interaction's matrix elements should be no trouble—it is fully renormalizable, like any singlet, uncharged vector meson, and obeys perturbation theory. It should also be worth checking on possible observable effects, e.g., χ creation through radiative scattering of highly energetic K mesons.

THE MUON AND THE FIFTH

Feinberg and Lederman[12] have summed up the situation with respect to an "anomalous" muon interaction. For an interaction with a vector field like our χ, they have (to first order in perturbation theory)

$$\delta m_\mu/m_\mu=\frac{3}{4\pi}\frac{g_\chi^2}{4\pi}\ln\left|\frac{\Lambda^2}{M_\chi^2}\right|,$$

which would now give us $\Lambda/M_\chi\geqslant 10^3$ for the muon and $\Lambda/M_\chi\sim 2$ for the baryons.

Considering that the χ is coupled to strangeness, we would have extremely small energy shifts in muonic atoms, there being no direct χ-mediated muon-nucleon interaction.

Serious limitations arise only from π-μ-ν decay and from the gyromagnetic ratio. The effective π-μ-ν coupling constant would be depressed by a factor

$$Z_2=1-\frac{\beta}{4\pi}\frac{g_\chi^2}{4\pi}\ln\left|\frac{\Lambda^2}{M_\chi^2}\right| \sim 1-\beta/\pi,$$

where β is of the order 1. This could depress $g_{\pi\mu\nu}$ by anything up to some 30%, as against an experimental uncertainty of 2%.

As to the muon magnetic moment, with

$$10^{-5}>\delta_g=\frac{g_\chi^2}{4\pi}\frac{1}{3\pi}\left(\frac{m}{M}\right)^2,$$

we would get $m/M_\chi\leqslant 0.02$, i.e., $M_\chi\sim 5$ BeV for a coupling of 0.3 to about 3 BeV if $g_\chi^2/4\pi\sim 0.1$.

Nevertheless, we do not feel that these two limitations, mainly the Z_2 value, should be taken as definitive evidence. The χ may be massive enough to agree with δg, and wave function renormalization effects may involve cutoff-dependent quantities besides the first-order term given above. To account for the experimental value of the muon pair production by neutrinos passing through matter, we do not assume the muon neutrino to be coupled to χ, and have therefore chosen the Mahmoud-Konopinsky model.

BOOTSTRAPS AND THE FIFTH

Glashow[5] has analyzed the mechanism through which a "spontaneous" breakdown of the symmetry could occur. The result shows that three possibilities exist: (a) a symmetric solution; (b) a nonsymmetric one with the [27] contributing; (c) octet dominance of the symmetry breaking; even in case (c), it is not clear that the solution should conserve iso-spin and Y; it could also keep only I_3 and Y and break **I**. There is also no reason for the emergence of Y and I_3 at the existing angles to electric charge in the Cartan subalgebra diagonal plane of SU_3.

Cutkosky and Tarjanne[6] have obtained stability against b, thus restricting the "choice" to a symmetric solution versus an [8]. Again, why should a breakdown occur, and why in the Y, **I** direction? Any dynamical model that does it starts from some "contaminated" multiplet-ϕ-ω mixing as suggested by Gell-Mann,[1] Sakurai, Salam, Katz and Lipkin, and others; or one in which the mass breaking has already occurred, as in Cutkosky's[13] or Capps',[14] where the pseudoscalar mesons are taken to have their physical masses to start with. Cutkosky and Tarjanne have to assume Y conservation at the start, and have no way of choosing between the Y and Q directions.[15]

In our model, Y would be picked and the rest would follow, with the g_χ coupling doing it. It would give larger mass splittings in the Y direction as against Q it would determine the emergence of the nonsymmetric solution as the preferred one—an important point as most studies show that the symmetric one has "much

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more probability" to occur. We would be left with the question of a reason for the existence of strangeness—having thus sizably reduced the extent of the mystery.

CAN THE ϕ BE THE XENODYNAMIC FIELD χ?

There is a slight chance that we may have already seen the χ field—as the ϕ (1020 MeV, 1^-) seems to be coupled to S indeed. The various ϕ-ω mixing theories, looking for a model in which $\phi\not\to 3\pi$ have arrived at an extremely small coupling to nucleons, of the order of 10^{-3} or 10^{-4}. If the ϕ is coupled to the strangeness current, it would have no ρ-π coupling, and the main virtual decay mode would thus disappear—as against the ω. The width of the ϕ is now thought to be about 3.1 ± 1.0 MeV, i.e., a minimum[16] of 2 MeV. This may be too large for a nonstrong interaction, though not by any appreciable factor; remembering the inconsistency between present theoretical computations and the π^0 width, we should not be surprised to have $\Gamma\sim1$ to 2 MeV.

If the ϕ is our field, where is the eighth component of the vector meson octet? This question makes the ϕ-χ identification a highly speculative supposition. Nevertheless, it is worth investigating a new resonance reported by the Syracuse-Brookhaven group.[17] In a missing mass plot of

$$K^-+p\to\Lambda+\text{neutrals},$$

they see a peak at 930 MeV. This is exactly the value we would have expected the eighth component to have according to the mass formula. Can this be really it?

The 3π plots where the ω was found do show a very slight bump at[18] 930 MeV though this may be an ordinary statistical deviation with no significance. On the other hand, it could be the $\pi^+\pi^0\pi^-$ decay mode of the $\eta(930,1^-)$ of our speculation. Its width should be somewhat larger than the ω, as it can have all the ω decay modes and also go into 5π, plus additional electromagnetic decays. It is not clear, however, that these electromagnetic decays—the only neutral modes it has—would suffice to make it appear in the above-mentioned missing mass plot, where the ω itself is not clearly seen. A favorable example is the charged 2π decay mode of the ω, which is important enough to appear in ρ plots; and the neutral modes of the η, all of them electromagnetic also, and appearing in the missing mass plot at the sides of the 930-MeV bump. Again, if R symmetry is meaningful for mesons, its decay into 3π would be forbidden by it, which would increase the neutral modes.

These considerations, even though speculative, have the advantage of pointing at possible checks of the χ meson idea—making the χ in all the experiments where the ϕ is produced. It may be a matter of accumulating more statistics, to cope with the relative smallness of g_χ and the corresponding cross sections—all of them should be a fraction of the ϕ's.

The connection with the muons, if it exists, should appear in radiative scattering of high-energy muon beams, where $K\bar{K}$ pairs should be produced through χ (if this is the ϕ, they should be relatively accessible). Another check would consist in measuring $\phi\to\mu^++\mu^-$ and comparing it with the similar e^++e^- result, where only electromagnetism operates.

Note added in proof. The possibility that the χ be massless would imply a relatively small xenomagnetic coupling, as pointed out to the author by Professor N. Ramsey. There may also be difficulties in reconciling its existence with the experimental limits on $\pi^0\to\gamma+\chi$ and with the results of electromagnetic renormalization theory and its successful predictions. On the other hand, a mass of $2m_\pi<m_\chi$ seems consistent with most experimental results, i.e., the ϕ is a good candidate. Since the 930-MeV meson seems to have decay modes which do not fit a Γ octet's eighth component, we would then have to return the ω to this role. The muon problem would probably require a higher mass. The author is indebted to S. Frautschi, R. Dashen, and D. Beder who have studied the detailed experimental implications.

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