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TOPOLOGICAL THEORY AND THE STANDARD ELECTROWEAK MODEL*

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ABSTRACT

Topological theory predicts 4 charged and 4 neutral electroweak vector bosons, together with 1 neutral scalar boson. There is a single coupling constant e allowing immediate prediction (up to radiative corrections), given the Fermi constant G , of a 75 GeV mass for left-handed charged vector bosons. We further predict vanishing of vector weak neutral-current coupling to charged leptons ($g_V = h_{VV} = h_{VA} = 0$). Dynamical assumptions motivated by meson spectra yield a vector boson spectrum whose 4 lowest-lying states correspond to the standard model with $\sin^2 \theta_W = 1/4 (M_{Z_0}^2 = 4/3 M_W^2)$. Couplings of the next (fifth) vector, a neutral Z_0' , are presented even though the Z_0' mass has not yet been calculated.

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† Participating guest at Lawrence Berkeley Laboratory.

This paper presents topological bootstrap-theory¹ predictions for the spectrum and couplings of electroweak bosons. We predict 8 vector bosons, 4 charged and 4 neutral, but with a single independent coupling constant which can be fixed by knowledge of the elementary electric charge e . The ratio of e to the leptonic coupling of the left-handed charged bosons $W^\pm$ leads to the relation $M_W^2 = e^2/\sqrt{2} G$, where G is the Fermi constant; experimental values for e and G yield $M_W \cong 75$ GeV. We shall furthermore show below that the coupling of any neutral vector boson (except the photon) to charged leptons is purely axial vector. Both predictions follow also in the standard Weinberg-Salam model² for the special value of the Weinberg angle $\theta_W = 30^\circ$ -- giving $\sin^2 \theta_W = 1/4$. In topological theory, however, there is no adjustable parameter analogous to θ_W .

Of the four neutral vector bosons, one is the photon and the other three we shall denote, in order of increasing mass, by Z_0 , Z_0' , Z_0'' . Topological theory in principle determines the masses and couplings of all three Z_0 bosons; in practice we presently lack sufficient understanding of topological dynamics to calculate all these quantities without further assumptions. We nevertheless present below some (hopefully plausible) dynamical assumptions which yield a Z_0 with the same leptonic couplings as the standard model if, again, in that model we set $\sin^2 \theta_W = 1/4$. We further, under these assumptions, obtain the Z_0' and Z_0'' couplings. The two predictions of the preceding paragraph (M_W and axial-vector Z_0 , Z_0' , Z_0'' coupling to charged leptons) do not depend on these extra assumptions.

We begin by describing the general structure of topological electroweak bosons; next come the additional assumptions needed for

a complete set of leptonic couplings; we conclude with a brief discussion of hadronic couplings.

Topological bootstrap theory¹ represents electroweak bosons as each built from a pair of oppositely-directed lines,³ in a sense similar to that in which a meson is built in Harari-Rosner diagrams⁴ from "quark" and "antiquark" lines. Because such lines carry a quantum number that can be taken as a definition of "fermion number", we shall call them "fermion" lines. Each fermion line effectively carries a pair of auxiliary orientations, one describable for reasons given below as "electrospin" and one associated with chirality; any fermion line is a $\begin{Bmatrix} c = \text{charged} \\ n = \text{neutral} \end{Bmatrix}$ electrospin doublet and also an $\begin{Bmatrix} o = \text{ortho} \\ p = \text{para} \end{Bmatrix}$ chiral doublet. The meaning of ortho and para is given in Refs. (1) and (5). At the elementary massless level there are then 16 electroweak bosons-- 8 scalars and 8 vectors as described below.⁶

Let us distinguish "fermion" from "antifermion", when denoting a pair of lines, by writing the former on the left and the latter on the right. Scalar bosons then have the topological structure oo and pp which, respectively, couple to leptons and to "quarks" as $1 + \gamma_5$ and $1 - \gamma_5$, while the vectors are $V_R \equiv op$ and $V_L \equiv po$. Because V_R couple to leptons and to "quarks" as $\gamma_\mu(1 + \gamma_5)$, we describe V_R and V_L , respectively, as "right-handed" and "left-handed".

Each of these scalars and vectors appears in 4 distinct electrospin forms -- an electroquartet. The $\begin{Bmatrix} c \\ n \end{Bmatrix}$ degree of freedom associates with electric charge: A c "fermion" ("antifermion") has charge $+1(-1)$, while an n "fermion" or "antifermion" is neutral. Thus the chirality and electric charge of the bosons usually designated by W^+ and W^- are carried, respectively, in topological theory by V_L^{cn} and V_L^{nc} . The

photon is

$$\gamma = (2/\sqrt{12}) \{ V_R^{cc} + V_L^{cc} \} \quad (1)$$

a neutral ortho-para symmetric vector coupling to electric charge, that is, to c directed lines.⁷ Electric charge is the single conserved quantity carried by topological electroweak bosons.

Elementary topological couplings among fermions and electroweak bosons are all $c \leftrightarrow n$ and $o \leftrightarrow p$ symmetric, a circumstance implying SU(2) electrospin symmetry (through the Paton-Chan argument⁸) and parity symmetry so long as junction lines are neglected. Topological theory contains junction lines as well as fermion lines and, because junction lines are exclusively $o \times c$ in auxiliary orientation, their electroweak couplings break both SU(2) and parity symmetries.⁵ All electroweak couplings are nevertheless determined by the single parameter e.

Closed-loop topologies can give masses to physical electroweak bosons and we assume that, because electric charge is the only conserved quantum number, Ward identities preserve masslessness only for the photon. There will then be 7 massive physical vector bosons, each of which must have "eaten" a scalar of matching charge in acquiring longitudinal helicity. One physical neutral scalar boson will survive; this paper will not consider its properties.

Topological couplings among electroquartets of elementary (massless) vector bosons are of the Yang-Mills type (equivalent to SU(2) $\times$ U(1) when the quartet is decomposed into triplet plus singlet) with left-handed vectors not coupled to right-handed. We assume that massive physical vector bosons are to a good approximation either right or left-handed, apart from states which mix with the photon. The 4 charged vectors, V_L^{cn} and V_L^{nc} , do not mix. Motivated by experimental

weak-interaction facts, we assume the junction-line parity asymmetry to generate substantially-higher masses for right-handed vector bosons than for left-handed. To the extent that the Fermi constant G is dominated by left-handed vectors, we then immediately relate G to the W mass:

$$G/\sqrt{2} = e^2/2M_W^2 \quad (2)$$

A feature of the weak neutral current follows immediately from the photon structure (1) even though the four neutral vectors have different masses and couplings. Any cc superposition orthogonal to the photon is proportional to

$$V_R^{cc} - V_L^{cc}$$

which couples like $\gamma_\mu Y_5$ (axial vector) to charged leptons. Because any nn vector boson fails to have charged-lepton coupling, topological theory is characterized by the absence of weak vector neutral-current coupling to charged leptons.

Although with less generality than the foregoing, it is possible to further contact the standard electroweak model through dynamical assumptions suggested by observed meson spectra. These assumptions, to be explained below, lead to certain easily-stated results:

If we define

$$W' \equiv (1/\sqrt{2}) \{ V_L^{cc} - V_L^{nn} \} \quad (3)$$

which transforms under $SU(2)$ as the neutral member of a left-handed W triplet, then the least-massive neutral vector boson after the photon is a mixture of W' and γ . We shall find

$$\begin{aligned} Z_0 &= (1/\sqrt{3}) \gamma - (2/\sqrt{3}) W' \\ &= (1/\sqrt{6}) \{ 2V_L^{nn} - V_L^{cc} + V_R^{cc} \} \end{aligned} \quad (4)$$

Comparison with the standard model again reveals the equivalent of a 30° Weinberg angle. The value $\sin^2 \theta_W = 1/4$ may be understood by recognizing that the topological photon is half left-handed and half right-handed and, simultaneously, half electrotriplet and half electrosinglet; the photon is 25% left-handed electrotriplet.

The next neutral vector boson is

$$Z'_0 = (1/\sqrt{3}) \{ V_L^{nn} + V_L^{cc} - V_R^{cc} \} \quad (5)$$

This is an $SU(2)_L$ singlet. Up to radiative corrections, Formula (5) determines all Z'_0 couplings to leptons in terms of e , just as Formula (4) gives Z_0 couplings. (Notice that both Z_0 and Z'_0 couplings to charged leptons are axial vector, as anticipated.) The most massive neutral vector is $Z''_0 = V_R^{nn}$, an $SU(2)_L$ singlet which couples only to neutral leptons.

The Z'_0 contribution to weak neutral currents depends inversely on $M_{Z'_0}^2$. The standard-model success -- without Z'_0 -- indicates a substantial $Z'_0 - Z_0$ mass gap; the current "best value" for $\sin^2 \theta_W$, in differing from $1/4$ by about 10%, may be signaling a Z'_0 mass roughly 3 times larger than M_{Z_0} .

Our guess at a dynamics which yields the above is motivated by the observed meson spectrum. We suggest an analogy between left-handed electroweak vector bosons and the lower-mass (up-down) first generation of mesons, while right-handed vectors are seen as analogous

to the higher-mass (charmed - strange) second generation. $SU(2)$ electrospin symmetry, while badly broken in general, is relatively good for the up- down hadrons, allowing recognition of "strong isospin" triplets and singlets. For example, $\rho^\pm$, ρ^0 is recognizable as a triplet and ω as a singlet. Thus

$$\begin{aligned}\rho^0 &\approx (1/\sqrt{2}) \{ cc - nn \}_{1st\ gen.} \\ \omega &\approx (1/\sqrt{2}) \{ cc + nn \}_{1st\ gen.}\end{aligned}\quad (6)$$

whereas

$$\begin{aligned}\phi &\approx \{ nn \}_{2nd\ gen.} \\ \psi &\approx \{ cc \}_{2nd\ gen.}\end{aligned}\quad (7)$$

Here c 1st gen. represents the p quark, n 2nd gen. the λ quark, etc.

Cylindrical closed-loop topologies, even when $SU(2)$ symmetric, mix cc with nn , in contrast to planar loops which do not.⁹ The examples (6) and (7) reflect a general rule that in the first generation the $SU(2)$ -symmetric cylindrical components are larger than any planar components that break $c \leftrightarrow n$ symmetry. In the second generation a large planar breaking of $c \leftrightarrow n$ symmetry overwhelms the cylinder.

We propose a similar rule for electroweak bosons: one of the two right-handed neutral vectors (V_R^{cc} or V_R^{nn}) shifts upward to a mass so far above the left-handed neutrals that (analogously to the ψ) it undergoes negligible mixing therewith; the other right-handed neutral vector shifts down into the vicinity of the left-handed neutral vectors (and so is analogous to the ϕ). Knowing the photon wave function [Eq. (1)] that must eventually emerge, we conclude that it is V_R^{cc} which shifts down. (V_R^{cc} couples to junction lines; V_R^{nn} does not.)

The second step also follows the meson pattern -- where the 2nd-generation state which has shifted downward mixes with the isosinglet 1st - generation state. For the mesons this mixing gives a (small) $\lambda\bar{\lambda}$ component to the ω and a (substantial) $\lambda\bar{\lambda}$ component to the η .

Analogously we assume that V_R^{cc} and the isosinglet left-handed vector -- orthogonal to the W^0 of Eq. (3) -- will mix. For reasons to become evident below we denote by B the lower-mass state resulting from this mixing and by Z'_0 the higher-mass state. We do not know, at this stage of the argument, the wave function of B and Z'_0 .

The final step involves $SU(2)$ - breaking for the left-handed vectors, allowing the isotriplet W^0 [Eq. (3)] to mix with isosinglets. We assume that the Z'_0 has been pushed to so high a mass that the W^0 mixes significantly only with the B . Since the photon [Eq. (1)] must result from this last mixing, the orthogonality between γ and Z'_0 determines uniquely the Z'_0 wave function to be that given by Eq. (5).

The B , furthermore, is uniquely determined to be

$$B = (1/\sqrt{2}) \{ 2V_2^{cc} + V_2^{cc} + V_2^{nn} \} \quad (8)$$

According to this latter equation the leptonic couplings of our B are exactly the same as those of the standard-model B : the coupling is to "weak hypercharge". The photon [Eq. (1)] is a linear combination of the B [Eq. (8)] and the W^0 [Eq. (3)], with the Z'_0 being the orthogonal combination, which turns out to be Eq. (4). If we neglect $SU(2)_L$ symmetry breaking except through the off-diagonal terms of the mass-squared matrix that mix B and W^0 , then that matrix is completely determined and one finds

$$M_{Z'_0}^2 = (4/3) M_{W^0}^2 \quad (9)$$

This condition also is obtained in the standard model with $\sin^2 \theta_W = 1/4$.

The foregoing sequential dynamics will be unrecognizable in a calculation where Ward identities are satisfied step-by-step; the photon mass then never moves from a zero value. On the other hand, in a calculation where junction-line couplings are treated on a different basis from purely fermion-line couplings, and where planar topologies are computed before cylindrical, the foregoing sequence is conceivable.¹⁰

Electroweak hadron couplings seem at first sight to provide a basis for experimental discrimination between topological theory and the standard model, because topological "quarks" are integrally charged (like leptons) and hadron junction lines not only carry electric charge but break parity together with isospin symmetry.⁵ At low momentum transfer, however, the combined electroweak couplings to topological "quarks" and to junction lines tend to be controlled by the total values of conserved hadron quantum numbers and thereby to be difficult to distinguish from couplings to fractionally-charged quarks in the standard model. At large momentum transfers to hadrons it is not yet known how to evaluate the experimental predictions of topological theory. In the near future, therefore, experimental evidence for or against our Z'_0 may prove the most significant test for topological theory. The simpler but higher-mass Z''_0 , which couples neither to junction lines nor to charged leptons, remains for the more distant future, together with the right-handed charged vectors.

FOOTNOTES AND REFERENCES

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