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Parity asymmetry from diquarks

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The "diquark" constituents of elementary hadrons in topological particle theory are shown to be a source of parity asymmetry. Electroweak-boson coupling to diquarks is unsymmetrical because of the junction-line end within each diquark. Also a consequence of the junction line is a relation between electric charge and topological "color" similar to that proposed by Han and Nambu for standard color.

In the standard electroweak model,[1] a preferred status is arbitrarily assigned to left-handed vector bosons, and in all Lagrangian generalizations of the standard model the breaking of parity symmetry continues to be *ad hoc*. Topological bootstrap theory also provides a standard-model generalization,[2,3] but from the bootstrap standpoint no aspect of nature is supposed arbitrary. This paper identifies in topological particle theory a nonarbitrary orientation asymmetry at the lowest level of the topological expansion which, although producing no strong-interaction parity violation, leads to unsymmetrical electroweak amplitudes. The root of the asymmetry lies in hadron junction lines and the coupling of electroweak bosons to "diquarks." Elementary hadrons are built from "quarks" and "diquarks," and each diquark constituent of a hadron contains the end of an unsymmetrical junction line which affects electroweak coupling even though the junction line is invisible in strong interactions. The asymmetry, in fact, stems from this invisibility.

Topological particle theory elevates Feynman graphs to a status more general than that of a Lagrangian and embellishes the graphs so the flow of *all* particle properties, not only momentum, achieves topological representation. The bootstrap seeks a *raison d'être* through consistency for all features of all particles. Although achievement of this objective remains incomplete, much of the usual arbitrariness in particle theory has by now been eliminated. Every Feynman graph is embedded in a globally oriented, bounded, two-dimensional "classical" surface[4] with graph ends on the surface boundary. *Other* lines within the surface or on its boundary carry spin, electrospin (similar to the isospin of standard theory), baryon number, lepton number, quark generation, "color," and lepton generation. Chirality is represented by local surface orientation.

Although we shall exhibit in Fig. 1 an example of all topological structures except those corresponding to quark and lepton generations and to quark color, the aggregate may overwhelm a reader exposed for the first time to topological representation of particles. So, by way of introduction, we call attention to a simpler but related scheme employed by 't Hooft[5] in connection with U(N) Yang-Mills theory—where each vector field is an $N \times N$ matrix. It was found useful by 't Hooft to associate each Feynman line belonging to a vector boson with two oppositely directed lines each carrying an N-valued index. A conserved internal quantum number flows along these auxiliary lines in the same sense as quark flavor is carried along

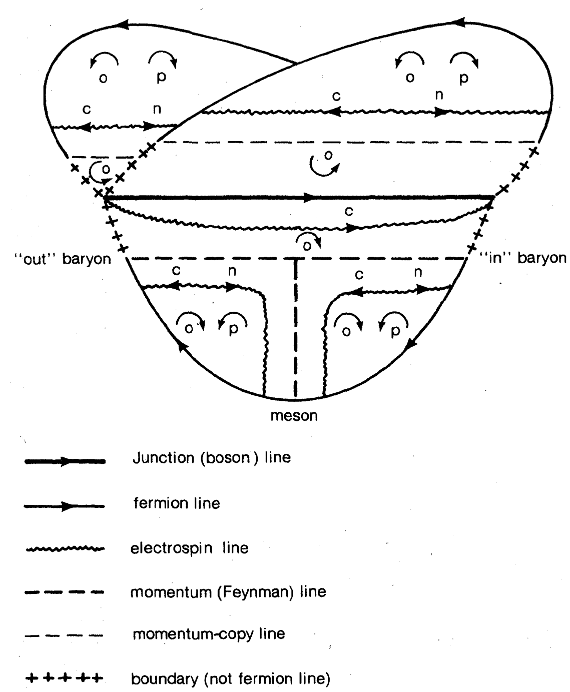

FIG. 1. "In"-baryon→"out"-baryon zero-entropy classical surface for coupling to a meson.

lines introduced earlier by Harari and Rosner.[5] Harari-Rosner quark-line diagrams did not include a Feynman graph to transport momentum, and 't Hooft's diagrams, although implicitly including the Feynman graph, did not include lines to transport spin, but the idea behind the devices of both 't Hooft and Harari-Rosner is maintained in the more general structures of topological particle theory.

An extension is our interpreting as topological *orientations* those indices attached to auxiliary lines. The two-valued index attached to our electrospin lines,[6] for example, describes the local line orientation—compared to the global orientation of the surface in which the line is embedded. The "twoness" of electrospin (isospin) is then no longer arbitrary and the source of both SU(2) symmetry and of symmetry breaking lies in topological-orientation reversals, as will be reviewed in what follows.

Spin, in topological particle theory, is carried by *fermion lines* along the boundary of the classical surface. The "twoness" of the Pauli spin index, just as for the electrospin index, corresponds to *local* fermion-line orientation, but each fermion line divides at its midpoint into two halves (usually associated with two different particles) which can be independently oriented. Spin is therefore not a conserved quantum number. Fermion lines are nevertheless continuous and correspondingly carry a conserved *fermion number f*, the direction of whose flow reflects the classical-surface *global* orientation, as will be exhibited when we discuss Fig. 1. For strong-interaction topologies, both halves of any fermion line share extra inherited orientations amounting to a flavor index; such fermion lines thereby can be described as "quark lines." But we must be careful to distinguish the quark half of a fermion line when the other half belongs to a nonhadron. A fermion half line belonging to an electroweak boson lacks any generation index and should not be called a quark. An elementary electroweak boson in topological particle theory includes the ends of two different fermion lines with opposite-induced orientations[2] as well as the ends of two electrospin lines.

"Quark flavor" is built from electrospin orientation in combination with "quark-generation" orientations (not to be discussed in this paper). Electric charge of topological quarks connects to electrospin and, as on any half of a fermion line, takes the values 0,1; development of an effectively-fractional quark electric charge relates to quark color and will be explained toward the end of our paper. We defer discussion of color to that point.

Half a decade ago extension of Harari-Rosner quark-line diagrams to baryons led several workers to the idea of *junction lines*[7] along which there meet three smooth pieces of the classical surface.[4] Also appearing in the classical surface are lines that control chirality[8]—in a manner reviewed below. Junction lines, fermion lines, electrospin lines, and momentum lines all end in clusters in a pattern illustrated in Fig. 1—an example we propose to examine in detail. A cluster of line ends, including a *single* momentum-line end which divides the remaining line ends into two subclusters called "half" and "antihalf," constitutes an elementary particle. Global orientation of the classical surface is responsible for the general feature that every elementary particle comes in two halves of opposite orientation. This feature was already an essential property of Harari-Rosner and 't Hooft diagrams.[5]

Junction lines have recently been renamed "boson" lines because, by virtue of *not* dividing into two separately orientable portions, they cannot carry spin. (We shall here use the names boson line and junction line interchangeably.) Boson lines are continuous and correspondingly carry one unit of a conserved "boson number" b in a direction dictated by the classical-surface global orientation. As explained in Ref. 9, linear combinations of boson and fermion number are identifiable as the familiar baryon and lepton numbers: $B=\frac{1}{2}f+\frac{1}{2}b$, $L=\frac{1}{2}f+\frac{3}{2}b$. (Readers are cautioned not to interpret b as "number of bosons." A baryon, for example, has $b=-1$ with $f=+3$.)

An arrow inherited from the classical-surface global orientation can be placed on any fermion or boson line so as to indicate the flow direction of f or b. The head of a line then carries $+1$ unit of f or b while the tail carries -1 unit. The global-orientation arrows are prominently featured in Fig. 1. Elementary-hadron halves may be characterized either as a fermionic quark (q) or a bosonic antidiquark ($\bar{d}$). The quark includes one fermion-line head ($f=+1$) and no boson-line ends ($b=0$). The antidiquark includes one boson-line head ($b=+1$) and two fermion-line tails ($f=-2$). This perhaps puzzling combination will be explained by Fig. 1. Elementary-hadron antihalves, $\bar{q}$ and d, have orientation reversed with respect to halves.

Elementary hadrons then fall into the four half-antihalf families $q\bar{q}$, qd, $\bar{d}\bar{q}$, and $\bar{d}d$. In this paper we shall refer to $q\bar{q}$ as an elementary meson, to qd ($\bar{d}\bar{q}$) as an elementary outgoing (ingoing) baryon and to $\bar{d}d$ as an elementary "hexon" (six line ends in addition to the Feynman end). Readers are cautioned that *physical* mesons and baryons are only remotely related to their elementary counterparts; details of the relationships are developed in Ref. 10. This paper is concerned with elementary interactions of elementary particles—the analog of a Lagrangian for "bare" fields. Even though lacking any corresponding local field, our elementary hadrons have status similar to that of elementary leptons and electroweak bosons.

Figure 1 represents an elementary interaction between a $q\bar{q}$ (meson), a $\bar{d}\bar{q}$ (in baryon), and a qd (out baryon). There is a single boson line but four separate fermion lines. The $q\bar{q}$ consists of two oppositely-directed fermion ends together with its Feynman end, while the qd consists of three fermion heads and one boson tail. Each fermion or boson end has an accompanying electrospin end.

Arrows on fermion and boson lines reflect global orientations of each separate smooth sheet of the classical surface, these orientations being coordinated so as to induce the same orientation of any junction line that unites them. A *single* overall global orientation then controls all induced fermion and boson arrows. In Fig. 1 the global orientation of each separate sheet may be read from the arrows along its boundary—induced arrows on fermion lines and on the junction line. Each sheet is divided into *locally* oriented patches which we discuss later.

Figure 1 also shows the division of a qd (outgoing baryon) by its Feynman (momentum) line into quark half plus diquark antihalf. The fermion head isolated on one side of the momentum line (the lower side as drawn) is the quark half, while the collection of two fermion heads and one boson tail, lying on the other (upper) side of the momentum line, constitute the diquark antihalf.

Because the focus of this paper will be on diquarks, we call attention to the lightly dashed lines within the diquark feathers of Fig. 1, which are labeled as "momentum-copy" lines. These lines were introduced in connection with chirality[8] and will be important to our story. In spite of their name, momentum-copy lines do not carry momentum, but their location on a diquark feather parallels that of the qd momentum line on the quark feather. Notice that each fermion line begins and terminates at the end either of a momentum line or of a momentum-copy line.

Figure 1 presents an example of a topology without complexity—a characteristic described as "zero entropy"—but many of its features persist in topologies of arbitrary complexity. Each oriented electrospin line, in particular, always connects the head of a fermion or boson line to the tail of a fermion or boson line. Reference 6 has characterized the electrospin orientation as c ("charged") if it agrees with its associated fermion or boson orientations. When there is disagreement, the electrospin orientation is designated as n ("neutral"). As illustrated in Fig. 1, any fermion end can be either c or n, but hadronic boson ends are always c (Ref. 4). This latter feature relates to the invisibility of boson lines in strong interactions, as discussed below and is responsible for the breaking of SU(2) fermionic electrospin symmetry.[6] Let us now review the broken-SU(2) story as an introduction to the breaking of parity symmetry.

For all strong-interaction topologies and for interactions *among* nonhadrons, electrospin lines with one end fermionic invariably have the other end also fermionic. This condition is required by consistency at the lowest levels of topological complexity and then is perpetuated by the connected sums which generate higher levels. A two-valued *fermion electrospin* may then be defined, which comes with a $c \leftrightarrow n$ (discrete) symmetry [which implies a continuous SU(2) symmetry].[6] This symmetry is broken by any topology containing an electrospin line with one end fermionic and the other belonging to a hadronic boson end, because the orientation of such an electrospin line cannot be reversed; it is frozen at c. The fermion end of such a line cannot participate in a general fermionic $c \leftrightarrow n$ inversion.

Why must there be any fermion-boson electrospin connection? The observed electric charges of baryons, spanning the interval 2, 1, 0, -1 rather than 3, 2, 1, 0, imply that photons couple to bosonic electrospin as well as to fermionic, and we show in this paper how such coupling can occur. From the bootstrap standpoint one requires a reason why such coupling *must* be present. We do not attempt here to provide such a reason. The photon end of an electrospin line being fermionic, it follows that fermionic electrospin symmetry is broken by the coupling of electroweak bosons to diquarks. This paper will demonstrate how such coupling also breaks parity symmetry.

How does parity appear in topological theory? Each fermion end carries, besides electrospin, a two-valued *chiral* degree of freedom.[8] In the Weyl basis for Dirac four-spinors associated with fermion lines, the two upper components, with projection operator $\frac{1}{2}(1+\gamma_5)$, are designated "ortho," while the two lower components, projected by $\frac{1}{2}(1-\gamma_5)$, are "para." The choice between ortho (o) and para (p) depend on the *local* orientation of that classical-surface patch which touches the fermion line near its end. As shown in Fig. 1, o (p) means agreement (disagreement) between local and global classical-surface orientations. For strong interactions and for interactions *among* nonhadrons there is a global $o \leftrightarrow p$ symmetry corresponding to parity invariance: Simultaneous reversal of all patch orientations in contact with fermion lines, together with inversion of all three-momenta, leaves an amplitude unchanged. Parity reverses all fermion chiralities.

What about classical patches touching junction lines? Strong-interaction topologies are all built by connected sum from zero-entropy surfaces such as that of Fig. 1, where each fermionic oriented patch is isolated from boson-line contact by either a momentum line or a momentum-copy line.[11] Quark fermion lines are isolated by the former, while diquark fermion lines are isolated by the latter. This isolation of fermion patches from boson lines is shown in Ref. 8 to persist *throughout all strong-interaction topologies and allows the parity-symmetry operation to ignore classical patches that touch boson lines.* For purely electroweak topologies—describing interaction among nonhadrons—a similar boson-line isolation occurs, parity inversion again being definable for purely fermionic patches. In this latter case, a Feynman line always separates boson patches from fermion patches.

Reference 8 proposed *not* locally orienting classical patches that touch boson lines (e.g., the three central patches of Fig. 1), but electroweak diquark interactions render such a rule untenable. Electroweak bosons are built from a pair of fermion-antifermion ends, and we shall show that a patch touching an electroweak boson sometimes will also touch the bosonic constituent of diquark. Now, as discussed in Ref. 4, the *rules of zero entropy preclude any hadronic degrees of freedom being attached to boson lines.* All hadron selection rules must reside in attributes of their fermion (quark) constituents. In other words, boson constituents of hadrons must be invisible at zero entropy. We must assign, once and for all, a *fixed* orientation to classical patches that touch hadronic boson lines, in the same sense that electrospin lines attached to hadronic boson lines have a fixed orientation (c). We adopt the rule that hadronic boson lines invariably carry an o label; that is, as in Fig. 1, classical patches that touch hadronic boson lines are always locally oriented in agreement with the global classical-surface orientation. *Whenever a fermion line and a hadronic boson line touch the same classical patch, parity symmetry is broken* because the o-p degree of freedom of the fermion end cannot be reversed. The fermion end can only have o chirality.

We shall find it is maintenance of meaning for hadron electric charge that requires fermion and boson lines to touch the same classical patch. If the total electric charge of a hadron is to be the sum of its constituent charges, the topological expansion must contain exactly one term coupling any c hadron constituent to a cc vector electroweak boson (both of whose electrospin ends are c).[12] The photon is such a boson and c can be read as "charged" because the photon couples to electric charge. The photon cannot couple to an n constituent; hence such a constituent carries zero electric charge. A total baryon charge is the sum of three fermion (quark) charges, each of which may be 0 or 1, plus a boson charge of -1. (Figure 1 shows why the boson orientation opposes the three fermion orientations.) How can the topology provide exactly one photon coupling to each c constituent and no more?

A preliminary consideration is that the classical surface, in order to allow coupling to all four constituents, must be more complex than that of Fig. 1, where the Feynman line is accessible to the quark but not to the fermion constituents of the diquark—these lying on feathers different from the feather carrying the Feynman graph. We require a single-sheeted surface as discussed in Ref. 13, but it has recently become appreciated that the proposal of Ref. 13 is inadequate. The reason is that a fermion-line boundary segment must pass continuously from the electroweak boson to the hadron in order to "transfer" the electroweak-boson spin and chirality. We illustrate this latter requirement in the lower portion of Fig. 2, which shows the "quark half" of the baryon. This portion is unchanged from Ref. 13 and is the same as a meson half. It is the "diquark half," to be discussed below, that requires modification. Only fermion lines are involved in the lower part of Fig. 2, and there is maintenance both of parity and electrospin symmetry. Reference 2 has pointed out that an electroweak boson is a vector (total spin 1) if its momentum line is a patch boundary, i.e., if one of its fermion ends is o and the other p, being right- (left-) handed if its fermion head (at the head of a fermion line) is $o(p)$, while its fermion tail is $p(o)$. The two ends touch patches of *opposite* local orientation. When these two patches have the *same* orientation, both o or both p, the electroweak boson carries zero total spin and has "scalar" coupling to the quark: $\frac{1}{2}(1+\gamma_5)$ if oo and $\frac{1}{2}(1-\gamma_5)$ if pp. [Vector couplings are $\gamma_\mu\frac{1}{2}(1+\gamma_5)$ if op and $\gamma_\mu\frac{1}{2}(1-\gamma_5)$ if po.]

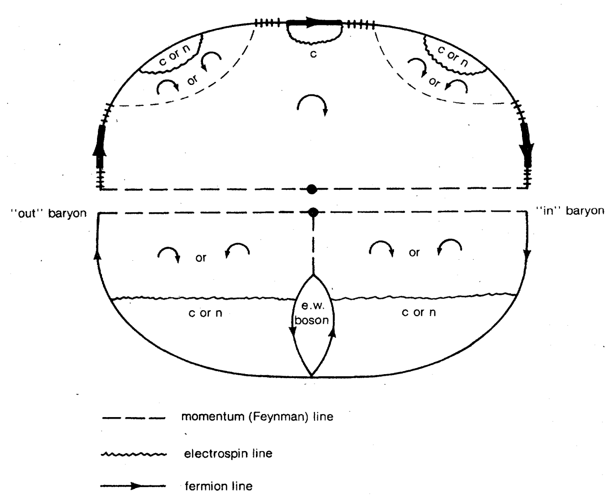

FIG. 2. (Lower) Electroweak-boson coupling to quark. (Upper) Passive diquark according to Ref. (13). (Figures in Ref. 13 show momentum-copy lines in "active" location.)

The diquark topology proposed in Ref. 13 is unable to accommodate electrospin coupling to the boson constituent because this constituent cannot absorb the spin and chirality of the electroweak boson. As in Fig. 2, there must be continuous fermion lines with one end in the electroweak boson and the other end in the hadron. The spin chirality of the electroweak boson, when coupling to a diquark, must always transfer to one of the fermionic constituents, regardless of which constituent supplies the electrospin. The full story here involves hermiticity (i.e., unitarity) and will be exposed elsewhere. Let us here simply take as a postulate that any elementary particle involved in an electroweak interaction shall have a fermion-line (boundary) connection to an electroweak boson.

The single-sheet baryon-current topology of Ref. 13 (see Fig. 2) is planar with a single connected boundary for the classical surface after a cut is made along the junction line. A single boundary component remains after any insertion of the electroweak boson according to the foregoing rule. Given the principle that electrospin lines do not cross Feynman lines it is then impossible for electrospin lines to connect the ends of the diquark's boson line to the fermion ends within the electroweak boson. The simplest diquark topology able to do the job is that of Fig. 3(a), where there are *two* disconnected boundary components after a cut along the junction line. (The three displayed segments of junction line are to be identified with each other.) The two "fermions" within the diquark are here distinguished from each other, one being disconnected (when a cut is made) along the junction line from the single fermion on the other side of the momentum line. Notice that the topology of the passive "connected fermion" in Fig. 3(a) is locally the same as in the zero-entropy topology of Fig. 1. Because no fermion lines in Fig. 3(a) lie in a patch that touches the junction line, there is no violation of parity symmetry, although $c \leftrightarrow n$ (fermion) electrospin symmetry has been broken: only cc electroweak bosons can couple to the boson-line electrospin.

Figure 3(b) couples the electroweak boson to the electrospin of the "disconnected fermion" within the diquark. Here both parity and electrospin symmetries are maintained. The passive connected fermion remains as in Fig. 3(a), and the junction line now also is passive.

How does the electroweak boson couple to the connected fermion within the diquark, which so far has remained passive? The disconnected fermion and the junction line now are both passive. Remembering that the momentum line of a *vector* boson separates patches of *opposite* local orientation, we achieve through Fig. 3(c) or Fig. 3(d) a unique topology for right- or left-handed vectors, respectively. By reversing orientation of the patch that does not touch the boson line, Fig. 3(c) or Fig. 3(d) also can accommodate an ortho-ortho electroweak *scalar* boson (the boson momentum line now separates patches of the *same* lo-

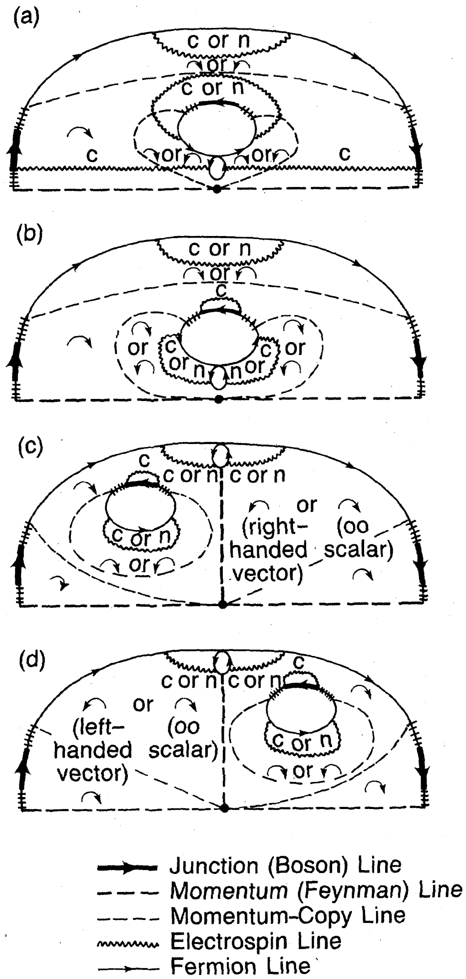

FIG. 3. Electroweak-boson coupling to diquark. (a) Electrospin coupling to junction line (spin-chirality coupling to disconnected fermion). (b) Electrospin (and spin-chirality) coupling to disconnected fermion. (c) Electrospin and right-handed spin-chirality coupling to connected fermion. (d) Electrospin and left-handed spin-chirality coupling to connected fermion.

cal orientation), but neither topology allows para-para, so parity symmetry is violated. There is a $1+\gamma_5$ "scalar" coupling to the connected fermion, but no $1-\gamma_5$ coupling. Parity violation has arisen because a fermion line and a boson line touch the same patch.

Two questions could be raised at this point:

(1) Why did we not insert the disconnected portion of boundary and junction line into a patch isolated from any fermion line? The answer is that two equivalent such patches are available [see Figs. 3(c) and (d)] so we would fail to achieve a unique vector coupling, and electric charge would lose meaning for baryons.

(2) Why do we insist on coupling scalar as well as vector bosons to hadrons? Here we recall the bootstrap reasoning of Ref. 3 which related a scalar boson having vacuum quantum numbers to a small violation of unitarity within the strong-interaction S matrix. It was essential that such a scalar couple to hadrons, the coupling constant being of order e, and no way was found to introduce the scalar except as one member of a boson multiplet that includes vectors. Such reasoning gives more urgency to hadronic scalar-boson coupling than to hadronic vector-boson coupling.

The diquark electroweak couplings proposed in Fig. 3 amplify the notion of topological color introduced in Ref. 4. Color 1 was there assigned to the fermion constituting the quark half of a hadron, while colors 2 and 3 were assigned to the two fermions of a diquark half. Although the shorthand notation of Fig. 4 places color 2 "close" to the boson line, within strong-interaction topologies colors 2 and 3 have symmetrical status. The electroweak proposal of this paper now breaks the 2-3 color symmetry, it being natural to designate by color 2 the *disconnected* fermion within the electroweakly interacting diquark. The *connected* diquark fermion then carries color 3.

Electroweak vector-boson couplings to hadronic fermions with color 1 and 3, have the same electrospin-symmetry form as their coupling to nonhadronic fermions. But cc vector bosons (both halves carry a c label) couple anomalously to color 2. Here two topologies must be added, one normal but the other controlled by boson-line electrospin which is always c at both ends regardless of the electrospin carried by the color 2 fermion line. The opposite boson orientation furthermore, gives a minus sign to the anomalous coupling. A normal cc vector-boson coupling to a $\left(\begin{smallmatrix}c\\n\end{smallmatrix}\right)$ fermion can be characterized as proportional to $\left(\begin{smallmatrix}1\\0\end{smallmatrix}\right)$, while the anomalous coupling is proportional to $\left(\begin{smallmatrix}-1\\-1\end{smallmatrix}\right)$. Thus the total photon coupling to color 2 has the form

$$\begin{bmatrix}1\\0\end{bmatrix}+\begin{bmatrix}-1\\-1\end{bmatrix}=\begin{bmatrix}0\\-1\end{bmatrix},$$

while the coupling to colors 1 and 3 is $\left(\begin{smallmatrix}1\\0\end{smallmatrix}\right)$. Such a scheme was long ago suggested by Han and Nambu[14] for otherwise standard quarks. Under circumstances where an average is to be taken over all three colors, the result is an effective coupling $\left(\begin{smallmatrix}2/3\\-1/3\end{smallmatrix}\right)$ to each hadronic fermion.

Scalar electroweak bosons, when cc, also couple anomalously to color 2 but further exhibit parity-violating

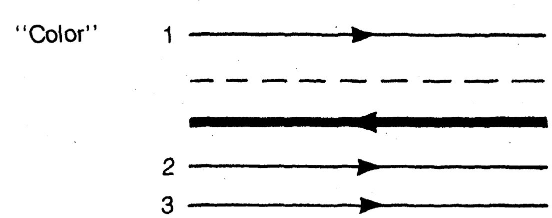

FIG. 4. Shorthand representation of topological color for the three fermion constituents of a baryon.

coupling to color 3 regardless of their electrospin. Elementary vector bosons do not violate parity through direct couplings, although interaction with scalars ultimately will cause *physical* vector bosons to distinguish left from right.

Given the significance of junction lines and the fact that standard field theories lack analogous ingredients (quark fields are recognizably analogous to the ends of quark lines), it is appropriate in conclusion to recall the bootstrap *raison d'être* of junction lines. Once fermion lines are located along the boundary of a classical surface, a unitarity consideration uncovered by Stapp[15] makes junction lines unavoidable. In the absence of junction lines and consequently with a smooth classical surface, all elementary particles would consist of a Feynman end plus two oppositely directed fermion-line ends; all elementary hadrons would be mesons. But then at the lowest level of topological complexity—the zero-entropy level where all Feynman graphs are planar and *o-p* labels are conserved—each closed Feynman loop is accompanied by a *single* fermion loop which comes with the minus sign characteristic of fermi statistics. The *contraction* of closed loops, an essential characteristic of zero entropy, would then be inconsistent. There would be conflict at the base of the topological expansion with the positivity requirements of unitarity.

The way out is to include the possibility of a positive-sign bosonic "diquark loop," which requires junction lines.[4] As noted above, the "chiral" and "electro" orientations of hadron junction lines must be "frozen," and this freezing we have seen here to break parity as well as electrospin symmetry.

Although this paper has focused on electroweak-boson coupling to diquarks when quark lines undergo no switch in color (i.e., $2\to2$, $3\to3$), it is necessary, also to accommodate electroweak coupling as quark color switches ($2\to3$, $3\to2$).[11] The classical surface then remains as described here, but charge-conjugation symmetry as well as parity symmetry becomes broken. The color-diagonal electroweak couplings described in this paper do not violate charge-conjugation symmetry.

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