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PARITY ASYMMETRY FROM "DIQUARKS"¹

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Abstract

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.

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In the standard electroweak model¹ 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.

Half a decade ago extension of Harari-Rosner dual diagrams⁴ to baryons led several workers to the idea of oriented junction lines⁵ along which there meet 3 smooth pieces of an abstract bounded surface subsequently called the "classical surface".⁶ The classical surface embeds a Feynman momentum-carrying graph together with charge-controlling lines that do not touch the Feynman graph. These lines are said to carry "electrospin"⁷ because of their connection with an SU(2) symmetry analogous to the isospin symmetry of standard Lagrangian theory. Electrospin symmetry will be reviewed in what follows. Also appearing on the classical surface are lines that control chirality⁸--in a manner reviewed below. Junction lines, electrospin lines and momentum lines all end in clusters on the classical-surface boundary 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, together with the associated boundary portion, constitutes an elementary particle.

Junction lines have recently been renamed "boson" lines because they carry no spin. (We shall here use the two names interchangeably.) Spin flows along oriented segments of the classical-surface boundary which are called "fermion" lines. Examples are given in Fig. 1. Each fermion line carries one unit of a conserved quantity f called "fermion number", while each junction (or boson) line carries one unit of a conserved "boson number", b . As explained in Ref. (9), linear combinations of boson and fermion number are identifiable as the familiar baryon and lepton numbers: $B = 1/2 f + 1/2 b$, $L = 1/2 f + 3/2 b$. For strong-interaction topologies, fermion lines are the quark lines of Harari and Rosner,⁴ but this paper is concerned with electroweak interactions of hadrons. We shall be careful to speak of the "quark" end of a fermion line only when this end belongs to a hadron. If the other end belongs to an electroweak boson, it should not be called a "quark".

The orientations of both fermion and boson lines are consistently induced by a global orientation of the classical surface. As illustrated by Fig. 1, each smooth sheet of the surface is oriented and the orientations of separate sheets are coordinated so as to induce the same orientation of any junction line which unites them. In Fig. 1 the global orientation of each sheet may be read from its boundary orientations, which simultaneously are the orientations of fermion lines and the junction line. Each sheet is divided into locally-oriented patches which we discuss later.

Figure 1 represents the interaction of a meson with "in" and "out" baryons. There is a single boson line but four separate fermion lines. The meson consists of two fermion ends together with its Feynman end, while each baryon consists of 3 fermion ends, a boson end and a Feynman end. Each fermion or boson end has an accompanying electrospin end.

Figure 1 also shows the division of a baryon by its Feynman (momentum) line into "quark" plus "diquark". Each elementary particle is divided into two "halves" by its Feynman line. Consider the "in" baryon of Fig. 1. The fermion end isolated on one

side of the momentum line (the lower side as drawn) is the "quark", while the collection of two fermion ends and one boson end, lying on the other (upper) side of the momentum line, constitute the "diquark". Both halves of a meson are "quarks"; those elementary hadrons, both of whose halves are "diquarks", are called baryoniums.⁶

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 chirality⁸ 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 baryon 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 (7) 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 .⁶ 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.⁷ 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 2-

valued fermion electrospin may then be defined, which comes with a $c \leftrightarrow n$ (discrete) symmetry (which implies a continuous $SU(2)$ symmetry).⁷ 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.* The photon end of an electrospin line

*From the bootstrap standpoint one requires a reason why such coupling must be present. We do not attempt here to provide such a reason.

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 2-valued chiral degree of freedom.⁸ In the Weyl basis for Dirac 4-spinors associated with fermion lines, the two upper components--with projection operator $1/2 (1 + \gamma_5)$ --are designated "ortho", while the two lower components--projected by $1/2 (1 - \gamma_5)$ --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 3-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".¹⁰ "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 3 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. (6), 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).¹¹ 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 3 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 3 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 4 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. (12), but it has recently become appreciated that the proposal of Ref. (12) 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. (12) 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.)

The "diquark" topology proposed in Ref. (12) 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. (12) (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. 3a, where there are two disconnected boundary components after a cut along the junction line. (The 3 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. 3a is locally the same as in the zero-entropy topology of Fig. 1. Because no fermion lines in Fig. 3a 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 3b 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. 3a, 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. 3c or Fig. 3d a unique topology for right or left-handed vectors, respectively. By reversing orientation of the patch that does not touch the boson line, Fig. 3c or Fig. 3d also can accommodate an ortho-ortho electroweak scalar boson (the boson momentum line now separates patches of the same local 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. 3c, 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. (6). "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-symmetric 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 $\begin{pmatrix} c \\ n \end{pmatrix}$ fermion can be characterized as proportional to $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$, while the anomalous coupling is proportional to $\begin{pmatrix} -1 \\ -1 \end{pmatrix}$. Thus the total photon coupling to color #2 has the form

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix} + \begin{pmatrix} -1 \\ -1 \end{pmatrix} = \begin{pmatrix} 0 \\ -1 \end{pmatrix}$$

while the coupling to "colors" #1 and #3 is $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$. Such a scheme was long ago suggested by Han and Nambu¹³ for otherwise standard quarks. Under circumstances where an average is to be taken over all 3 "colors", the result is an effective coupling

$$\begin{pmatrix} 2/3 \\ -1/3 \end{pmatrix} \text{ to each hadronic fermion.}$$

Scalar electroweak bosons, when cc, also couple anomalously to color #2 but further exhibit parity-violating coupling to color #3 regardless of their electrosin. 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 Stapp¹⁴ 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 2 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.⁶ 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 electrosin symmetry.

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FIGURE CAPTIONS

1. "In"-baryon $\rightarrow$ "out"-baryon zero-entropy classical surface for coupling to a meson.
2. (Lower) Electroweak-boson coupling to "quark".
(Upper) Passive "diquark" according to Ref. (12). (Figures in Ref. (12) show momentum-copy lines in "active" location.)
3. Electroweak-boson coupling to "diquark".
(a) Electrosipin coupling to junction line (spin-chirality coupling to "disconnected fermion").
(b) Electrosipin (and spin-chirality) coupling to "disconnected fermion".
(c) Electrosipin and right-handed spin-chirality coupling to "connected fermion".
(d) Electrosipin and left-handed spin-chirality coupling to "connected fermion".
4. Shorthand representation of topological "color" for the three fermion constituents of a baryon.

- > Junction (boson) line
- > fermion line
- ~~~~~ electrospin line
- momentum (Feynman) line
- momentum copy line
- +++++ boundary (not fermion line)

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Figure 1

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Figure 2

Figure 3

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Figure 4

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