

A topological model of composite preons

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We describe a simple model, based on the preon model of Shupe and Harari, in which the binding of preons is represented topologically. We then demonstrate a direct correspondence between this model and much of the known phenomenology of the Standard Model. In particular we identify the substructure of quarks, leptons and gauge bosons with elements of the braid group B_3 . Importantly, the preonic objects of this model require fewer assumed properties than in the Shupe/Harari model, yet more emergent quantities, such as helicity, hypercharge, and so on, are found. Simple topological processes are identified with electroweak interactions and conservation laws. The objects which play the role of preons in this model may occur as topological structures in a more comprehensive theory, and may themselves be viewed as composite, being formed of truly fundamental sub-components, representing exactly two levels of substructure within quarks and leptons.

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I. INTRODUCTION

The Standard Model (SM) provides an extremely successful and simple means of classifying and understanding the physical processes which fill the Universe. However the existence of many seemingly arbitrary features hints at a more fundamental physical theory from which the SM arises. Considering the successful series of ideas leading through molecules, to atoms, nuclei, nucleons, and quarks, it was perhaps inevitable that a model based on compositeness of quarks and leptons would be developed. The first such was proposed by Pati and Salam [1] in 1974, however it lacked any real explanatory power. Pati and Salam gave the name *preons* to their hypothetical constituent particles, and this name was gradually adopted to refer to the sub-quark/sub-lepton particles of any model. Other notable preon models were developed by several authors (e.g. [2]), but it is the so-called Rishon Model, proposed simultaneously by Harari and Shupe [3, 4] which will be of most interest to us here. In Harari's more commonly quoted terminology, this model involves just two kinds of 'rishons', one carrying an electric charge of $+e/3$ where $-e$ is the charge on the electron, the other neutral. The rishons combine into triplets, with the two "three-of-a-kind" triplets being interpreted as the ν_e and e^+ , and the permutations of triplets with an "odd-man-out" being interpreted as the different colours of quarks. Equivalent combinations can be formed from the anti-rishons to create the remaining fermions and anti-fermions, such as the e^- and $\bar{\nu}_e$. Certain combinations of rishons and anti-rishons were also suggested to correspond with gauge bosons.

The rishon model accounted for many aspects of the SM, including the precise ratios of lepton and quark electric charges, and the correspondence between fractional elec-

tric charge and colour charge. Unfortunately, as originally proposed it also had several problems, including the lack of a dynamical framework, and the lack of an explanation as to why the ordering of rishons within triplets should matter. A charge called "hypercolour" was proposed to solve these problems [5]. The introduction of hypercolour implied the existence of "hypergluons" and some QCD-like confinement mechanism for the rishons. Hence, the simplicity of the original model was reduced, and many of the fundamental questions about particles and interactions were simply moved to the realm of rishons, yielding little obvious advantage over the SM. Furthermore preon models were never able to adequately answer several fundamental questions, such as how preons confined at all length scales experimentally probed can form very light composites (see e.g. [6] for an attempt to address this issue).

This article presents an idea based on the original rishon model (without hypercolour), which we call the Helon Model. The reader should note the subtle yet important distinction that this is not a preon model *per se*, based upon point-like particles, but rather a preon-*inspired* model, which may be realised as a topological feature of some more comprehensive theory. For this reason we do not believe that the objections levelled at the rishon model and other preon models should be assumed, *a priori*, to be relevant to the helon model. A thorough investigation of such issues will be undertaken in subsequent work, however they are beyond the scope of the current article. Here we simply present a pedagogical introduction to the helon model, and describe how various features of the standard model emerge from it.

II. THE HELON MODEL

Let us now introduce our topologically-based toy model of quarks, leptons, and gauge bosons. It is convenient to represent the most fundamental objects in this

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model by twists through $\pm\pi$ in a ribbon. For convenience let us denote a twist through π as a “dum”, and a twist through $-\pi$ as a “dee” (U and E for short, after Tweedle-dum and Tweedle-dee [7]). Generically we refer to such twists by the somewhat whimsical name “tweedles” [8]. We hope to deduce the properties of quarks and leptons and their interactions from the behaviour of their constituent tweedles, and to do so we shall employ a set of assumptions that govern their behaviour:

1) Unordered pairing: *Tweedles combine in pairs, so that their total twist is 0 modulo 2π , and the ordering of tweedles within a pair is unimportant.* The three possible combinations of UU , EE , and $UE \equiv EU$ can be represented as ribbons bearing twists through the angles $+2\pi$, -2π , and 0 respectively. A twist through $\pm 2\pi$ is interpreted as an electric charge of $\pm e/3$. We shall refer to such pairs of tweedles as *helons* (evoking their helical structure) and denote the three types of helons by H_+ , H_- , and H_0 .

2) Helons bind into triplets: *Helons are bound into triplets by a mechanism which we represent as the tops of each strand being connected to each other, and the bottoms of each strand being similarly connected.* A triplet of helons may split in half, in which case a new connection forms at the top or bottom of each resulting triplet. The reverse process may also occur when two triplets merge to form one triplet, in which case the connection at the top of one triplet and the bottom of the other triplet “annihilate” each other.

The arrangement of three helons joined at the top and bottom is equivalent to two parallel disks connected by a triplet of strands. In the simplest case, such an arrangement is invariant under rotations through angles of $2\pi/3$, making it impossible to distinguish the strands without arbitrarily labelling or colouring them. However we can envisage the three strands crossing over or under each other to form a braid. The three strands can then be distinguished by their relative crossings. We will argue below that braided triplets represent fermions, while unbraided triplets provide the simplest way to represent gauge bosons.

3) No charge mixing: *When constructing braided triplets, we will not allow H_+ and H_- helons in the same triplet. H_+ and H_0 mixing, and H_- and H_0 mixing are allowed.*

4) Integer charge: *All unbraided triplets must carry integer electric charge.*

Assumption 1) is unique to the helon model, as it reflects the composite nature of helons, however assumptions 2), 3) and 4) are merely restatements in a different context of assumptions that Shupe and Harari made in their work. We will require one further assumption, however it will be left until later, as it can be better understood in the proper context.

In terms of the number of fundamental objects, the helon model is more economical than even the rishon model, albeit at the cost of allowing helons to be composite. This seems a reasonable price to pay, as the tweedles are ex-

tremely simple, being defined by only a single property (i.e. whether they twist through $+\pi$ or $-\pi$). This may be interpreted as representing exactly two levels of substructure within quarks and leptons.

The helon model also improves on the original rishon model by explaining why the ordering of helons (which are analogous to rishons) should matter. There are three permutations of any triplet with a single “odd-man-out”. Without braiding we cannot distinguish these permutations, by the rotational invariance argument above. However, if we allow braiding, the strands (and hence permutations) become distinct, in general. We may associate these permutations with the three colour charges of QCD, just as was done in the rishon model, and write the helons in ordered triplets for convenience. The possible combinations and their equivalent quarks are as follows (subscripts denote colour):

$$\begin{array}{lll} H_+H_+H_0 \begin{pmatrix} u_B \\ \bar{d}_B \end{pmatrix} & H_+H_0H_+ \begin{pmatrix} u_G \\ \bar{d}_G \end{pmatrix} & H_0H_+H_+ \begin{pmatrix} u_R \\ \bar{d}_R \end{pmatrix} \\ H_0H_0H_+ \begin{pmatrix} \bar{u}_B \\ d_B \end{pmatrix} & H_0H_+H_0 \begin{pmatrix} \bar{u}_G \\ d_G \end{pmatrix} & H_+H_0H_0 \begin{pmatrix} \bar{u}_R \\ d_R \end{pmatrix} \\ H_-H_-H_0 \begin{pmatrix} \bar{u}_B \\ d_B \end{pmatrix} & H_-H_0H_- \begin{pmatrix} \bar{u}_G \\ d_G \end{pmatrix} & H_0H_-H_- \begin{pmatrix} \bar{u}_R \\ d_R \end{pmatrix} \\ H_0H_0H_- \begin{pmatrix} d_B \\ \bar{u}_B \end{pmatrix} & H_0H_-H_0 \begin{pmatrix} d_G \\ \bar{u}_G \end{pmatrix} & H_-H_0H_0 \begin{pmatrix} d_R \\ \bar{u}_R \end{pmatrix} \end{array}$$

while the leptons are:

$$H_+H_+H_+ (e^+) \quad H_0H_0H_0 (\nu_e) \quad H_-H_-H_- (e^-)$$

Note that in this scheme we have created neutrinos, but not anti-neutrinos. This has occurred because the H_0 helon is its own anti-particle. This apparent problem will be turned to our advantage in Section III. Note also that we have not ascribed any of the usual quantum numbers (such as mass or spin [13]) to the helons. It is our expectation that spin, mass, hypercharge and other quantities emerge dynamically, just like electric charge, as we arrange helons into more complex patterns.

It is interesting to note that three helons seems to be the minimum number from which a stable, non-trivial structure can be formed. By stable, we mean that a physical representation of a braid on three strands (e.g. made from strips of fabric) cannot in general be smoothly deformed into a simpler structure. By contrast, such a physical model with only two strands can always be untwisted.

III. PHENOMENOLOGY OF THE HELON MODEL

A braid on n strands is said to be an element of the braid group B_n . Given any element of B_n , it is also possible to create a corresponding anti-braid, which is the top-to-bottom mirror image of that braid, and is also an element of B_n (it is therefore merely a matter of convention what we call a braid or an anti-braid). If we join the strands of a braid with those of its top-to-bottom mirror image (i.e. we take the braid product [9]) we obtain a structure which can be deformed into the trivial braid. Conversely, if the strands of a trivial braid are crossed so as to form a braid, an anti-braid must also be

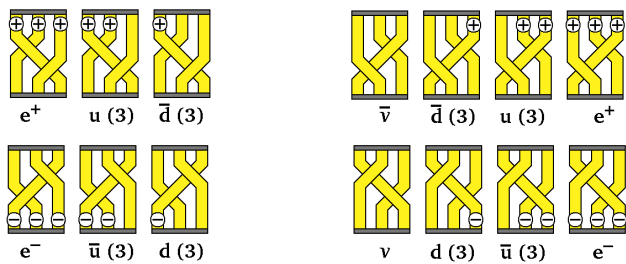


FIG. 1: The fermions formed by adding zero, one, two or three charges to a neutral braid. Charged fermions come in two handedness states each, while ν and $\bar{\nu}$ come in only one each. (3) denotes that there are three possible permutations, identified as the quark colours. The bands at top and bottom represent the binding of helons.

formed. Thus if we assign a quantity $\beta = +1$ to braids and $\beta = -1$ to anti-braids, $N_B = \sum \beta$ is conserved in splitting and joining operations (where the sum is taken over all braids and anti-braids present). These properties are reminiscent of the relationship between particles and anti-particles, and so it is natural to use the top-to-bottom mirroring of braids as a model for particle-anti-particle interchange, or C inversion. In addition, given any element of B_n , its left-to-right mirror image may be formed. We will call these the *left-handed* and *right-handed* forms of a braid. It seems natural to equate these with particles and anti-particles having positive and negative helicity. From the discussion above, all fermions and their anti-particles are represented by braids which are elements of B_3 .

Let us construct the first-generation fermions with positive charge as shown on the right of Figure 1 (we are using a basic braid, like that used to plait hair, for illustrative purposes, however an arbitrary number of crossings is possible). This yields the positron, up quark, anti-down quark, and anti-neutrino. Now let us construct the negatively-charged fermions by taking the top-to-bottom mirror images of the positively charged fermions. We have constructed the positively charged fermions by adding positive charges (dees) to a right-handed braid, and their anti-particles by adding negative charges (dums) to a left-handed anti-braid. This decision was of course completely arbitrary. We can also add dees to a left-handed braid and dums to a right-handed anti-braid. If we do this, we create all the possible charge-carrying braids in two different handedness states exactly once, but following the same procedure for the uncharged braids (i.e. neutrinos and anti-neutrinos) would mean duplicating them, since this second pair of neutral leptons is identical to the first pair, rotated through $\pm\pi$. In other words, to avoid double-counting we can only construct the (anti-)neutrino in a (right-)left-handed form, while all the other fermions come in both left- and right-handed forms. This pleasing result is a direct consequence of the fact that we construct the neutrino and anti-neutrino

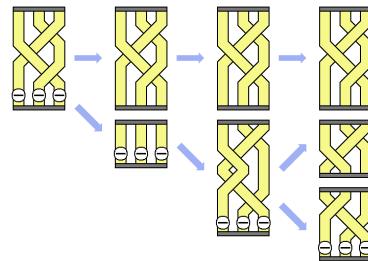


FIG. 2: A representation of the decay $\mu \rightarrow \nu_\mu + e^- + \bar{\nu}_e$, showing how the substructure of fermions and bosons demands that charged leptons decay to neutrinos of the same generation.

from the same sub-components (by contrast the rishon model used neutral rishons for the ν_e and neutral anti-rishons for the $\bar{\nu}_e$).

If we perform C and P operations on any braid (except a ν or $\bar{\nu}$, on which we cannot perform P) we obtain the braid diagonally opposite it in Figure 1. We may define a further operation which consists of rotating a braid clockwise or anti-clockwise through π , and reversing the sign of all charges. This operation will be called T, and we note that performing C, P, and T in any order on a braid leaves that braid unchanged.

Having constructed the quarks and leptons, we now turn our attention to their interactions via the electroweak and colour forces.

The Electroweak Interaction We shall begin by constructing the bosons of the electroweak interaction, γ , W^+ , W^- , and Z^0 . The W^+ and W^- may be regarded as a triplet of H_+ s and a triplet of H_- s respectively. We can create neutral bosons from a triplet of similar helons in two ways. One is as a triplet of untwisted helons, the other as a triplet of “counter-twisted” helons (that is, each helon carries explicit left-handed and right-handed twists). We shall claim that the former is the photon, the latter is the Z^0 (we may also speculate that deforming an untwisted helon into a counter-twisted helon, or vice-versa, accounts for the Weinberg mixing between the Z^0 and the photon [14]). What sets bosons apart from fermions (i.e. so that a γ is distinct from a neutrino, and a W^\pm is distinct from an e^\pm) is that the strand permutation induced by the braid that forms a boson is the identity permutation. The simplest braid that fulfills this criterion is the trivial braid, as in Fig. 3.

All interactions between helons can be viewed as cutting or joining operations, in which twists (tweedles) may be exchanged between helons. These operations define basic vertices for helon interactions. By combining three of these basic helon vertices in parallel we construct the basic vertices of the electroweak interaction (Figure 4). Crossing symmetries of the helon vertices automatically imply the usual crossing symmetries for the electroweak vertices.

We can represent higher generation fermions by allow-

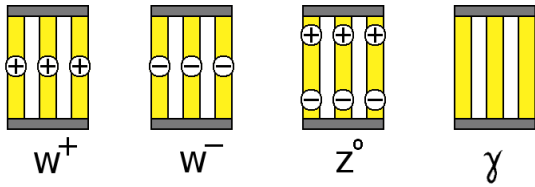


FIG. 3: The bosons of the electroweak interaction. Notice that the Z^0 and the photon can deform into each other.

ing the three helons to cross in more complicated patterns. Thus all fermions may be viewed as a basic neutrino “framework” to which electric charges are added, and the structure of this framework determines to which generation a given fermion belongs. If, say, a muon emits charge in the form of a W^- boson, the emission of this (trivially braided) boson does not affect the fermion’s braiding structure. Therefore the muon loses charge but does not change generation, and must transform into a muon-neutrino. Likewise, tau-neutrinos may only transform into tau particles and electron-neutrinos may only transform into electrons. A similar argument applies to quarks, although the mechanism by which the Cabibbo angles become non-zero is not immediately apparent. Notice that since W^\pm bosons carry three like charges, such processes will change quark flavour but not colour.

The Colour Interaction We have thus far described electroweak interactions as splitting and joining operations on braids. We may similarly represent colour interactions physically, this time as the formation of a “pancake stack” of braids. Each set of strands that lie one-above-the-other can be regarded as a “super-strand”, with a total charge equal to the sum of the charges on each of its component strands. If we represent braids as permutation matrices, with each non-zero component being a helon, we can easily represent the colour interaction between fermions as the sum of the corresponding matrices. For instance a red up quark, and an anti-red anti-up combining to form a neutral pion could be represented as

$$\begin{aligned} & \begin{bmatrix} 0 & 0 & H_0 \\ H_+ & 0 & 0 \\ 0 & H_+ & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & H_0 \\ H_- & 0 & 0 \\ 0 & H_- & 0 \end{bmatrix} \\ &= \begin{bmatrix} 0 & 0 & H_0 + H_0 \\ H_+ + H_- & 0 & 0 \\ 0 & H_+ + H_- & 0 \end{bmatrix} \quad (1) \end{aligned}$$

where the sum of two helons on the right-hand-side denotes a super-strand composed of a pair of helons. In this case all three super-strands have zero net charge. In this way hadrons can be regarded as a kind of superposition of quarks. We can now introduce our last assumption.

5) Charge equality: *When two or more braids are stacked, they must combine to produce the same total charge on all three super-strands.*

It is obvious that leptons trivially fulfill this criterion,

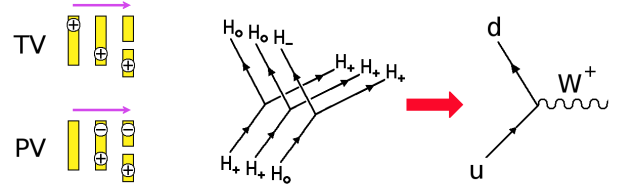


FIG. 4: The charge transferring vertex (TV) and the polarising vertex (PV) are basic helon vertices from which the electroweak basic vertices can be formed.

and will therefore not partake of the colour interaction. The reader may verify that quarks will naturally form groupings with integer electric charge, which are colour-neutral, for example three quarks forming a proton:

$$\begin{aligned} d_B + u_R + u_G &= \begin{bmatrix} 0 & 0 & H_0 \\ H_0 & 0 & 0 \\ 0 & H_- & 0 \end{bmatrix} \\ &+ \begin{bmatrix} 0 & 0 & H_0 \\ H_+ & 0 & 0 \\ 0 & H_+ & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & H_+ \\ H_0 & 0 & 0 \\ 0 & H_+ & 0 \end{bmatrix}. \quad (2) \end{aligned}$$

In QCD there are eight gluons. Two of these are superpositions of like colour/anti-colour states, which we may visualise as triplets with some untwisted strands, and some counter-twisted strands (strands with explicit positive and negative twist, as per the description of the Z^0 , above). The remaining six are “pure” unlike colour/anti-colour pairings, which we can visualise as the six permutations of one H_+ , one H_0 , and one H_- .

Hypercharge Recall that we assigned $\beta = +1$ to the braids on the top row of Figure 1, and $\beta = -1$ to the braids on the bottom row. This effectively distinguishes between fermions with a net positive and net negative charge. To distinguish between quarks and leptons the number of odd-men-out within any triplet, divided by the number of helons within a triplet suggests itself as a useful quantity (taking a value of 0 for leptons and 1/3 for quarks). However this quantity does not distinguish between a particle and its anti-particle. To rectify this shortcoming we will define a new quantity, given by one-third the number of “more positive” helons, minus one-third the number of “less positive” helons. We shall denote this quantity by the symbol Ω . To clarify, H_+ helons are considered “more positive” than H_0 helons, which are “more positive” than H_- helons. If $N(H_+)$ is the number of H_+ helons, $N(H_0)$ the number of H_0 s and $N(H_-)$ the number of H_- s within a triplet, and remembering that H_+ and H_- helons never occur within the same braided triplet, we may write

$$\Omega = \beta \left(\frac{1}{3}N(H_+) + \frac{1}{3}N(H_-) - \frac{1}{3}N(H_0) \right). \quad (3)$$

Hence we have $\Omega = +1$ for the e^+ , $\Omega = +1/3$ for the u , $\Omega = -1/3$ for the \bar{d} , and $\Omega = -1$ for the anti-neutrino. For the electron, anti-up, down, and neutrino the signs are reversed. With this definition, noting that $N(H_0) = 3 - (N(H_+) + N(H_-))$ and the total electric charge of a fermion is given by

$$Q = \beta \left(\frac{1}{3}N(H_+) + \frac{1}{3}N(H_-) \right), \quad (4)$$

it is easy to show that

$$Q = \frac{1}{2}(\beta + \Omega). \quad (5)$$

The values of Ω and β for the second and third-generation fermions are the same as those of their first-generation counterparts. For the quarks and anti-quarks Ω reproduces the SM values of strong hypercharge, while for the leptons β reproduces the SM values of weak hypercharge. Within the SM, strong hypercharge is defined in terms of baryon number, strangeness, charm, bottomness and topness as $Y = A + S + C + B + T$. In the helon model Ω plays a role equivalent to baryon number, thus $Y = \Omega$ for quarks, and there are no analogues of S , C , B , or T . This should be viewed not as a deficiency, but as a simplification, reminiscent of that recently proposed by Robson [10]. Similarly, within the SM weak hypercharge for leptons is defined in terms of electron number, muon number, and tau number as $y = -(L_e + L_\mu + L_\tau)$. In the helon model β plays a role equivalent to lepton number, thus $y = \beta$ for leptons. We also observe that for quarks $\beta/2$ reproduces the values of the third component of strong isospin, while for leptons $\Omega/2$ reproduces the values of the third component of weak isospin (in short, the roles of β and Ω as isospin and hypercharge are reversed for quarks and leptons). With these correspondences the Gell-Mann–Nishijima relation $Q = I_3 + Y/2$ for quarks may trivially be derived from Eq. (5)

It should be noted that in addition to the absence of analogues of S , C , B , or T , in the helon model the second and third-generation quarks carry non-zero values of strong isospin. Hence the c - s and t - b pairs appear to be strong isospin doublets, like the u - d pair. By contrast, in the SM this view is rejected, and the second and third-generation quarks are assigned $I_3 = 0$ due to the large differences in mass between the c and s quarks, and between the t and b quarks. We shall make no further comment on this point, other than to suggest that until a reliable way of calculating the quark masses from first principles is found, we cannot exclude the possibility that the perceived connection between mass and isospin (based initially on the example of the proton and neutron, which are now known to be composite) is incomplete.

Conservation of lepton and baryon number As we noted earlier braids are conserved, that is, braids and anti-braids are created and destroyed together, from trivial braids (i.e. bosons). This allows for pair annihilation and creation of fermions within the helon model.

Let x and y represent triplets of helons, and let $N_B(x)$

and $N_{\bar{B}}(y)$ be, respectively, the number of braids (composed of the triplet x and anti-braids composed of the triplet y (e.g. $N_{\bar{B}}(H_-H_-H_-)$ is the number of anti-braids composed of three H_- helons). Furthermore let $N(f)$ be the number of, and $\beta(f)$ be the value of β associated with, fermions of type f . Then, for an arbitrary collection of leptons, the total lepton number is

$$\begin{aligned} L &= \beta(e^+)N(e^+) + \beta(e^-)N(e^-) \\ &\quad + \beta(\bar{\nu}_e)N(\bar{\nu}_e) + \beta(\nu_e)N(\nu_e) \\ &= N_B(H_+H_+H_+) + N_B(H_0H_0H_0) \\ &\quad - N_{\bar{B}}(H_-H_-H_-) - N_{\bar{B}}(H_0H_0H_0) \\ &= N_B - N_{\bar{B}} \\ &= N_B^{\text{Total}} \end{aligned} \quad (6)$$

and so conservation of braids implies conservation of lepton number. This argument can easily be refined to account for the separate conservation of electron number, muon number, and tau number. A similar argument applies to quarks and baryon number.

IV. UNRESOLVED ISSUES

There are three significant issues the helon model has not yet addressed: the origin of spin, the origin of mass, and the nature of Cabbibo-mixing.

At the outset we hoped that spin would be emergent. Thus far we have been partly successful, identifying helicity of helon triplets, but not spin itself. It may be tempting then to assume that helons carry spin- $\frac{1}{2}$, and combine to form spin- $\frac{1}{2}$ composites. However this would not explain what spin is, would complicate the model, and would necessitate further assumptions to explain why helons never combine to form spin- $\frac{3}{2}$ states. It therefore seems reasonable to press ahead in the hope that spin will emerge as a consequence, rather than an assumption, of a dynamical theory based on the helon model.

We can speculate briefly on the origin of mass by noting that the helons within a fermion are represented as crossing each other to form structures which are elements of B_3 . Similarly, when a helon is twisted, its left and right edges cross each other, forming an object equivalent to a generator of B_2 . Therefore twisting (electric charge) and braiding are fundamentally the same process. Since the simplest fermions (neutrinos) are also the least massive fermions, and more complex braiding patterns correspond with higher generations (and hence greater mass) we propose that, roughly speaking, the more non-trivial the crossings in a fermion's substructure, the greater its mass. Much work will be needed to develop and test this idea quantitatively. Connected to the issue of mass is that of gravity. We note that our construction of the gauge bosons did not include a helon triplet that corresponds to the graviton (or for that matter, the Higgs). However gravity and the helon model may arise as separate parts of some more comprehensive theory (see Sec. V

for further discussion of this possibility).

Cabbibo-mixing may be related to the presence of H_0 helons within quarks. This would lead to an obvious connection between Cabbibo-mixing and neutrino oscillations, and explain why charged leptons do not mix between generations. A modification of the helon model in which the presence of H_0 helons within a triplet enable inter-generational mixing therefore seems like a reasonable avenue of future enquiry.

V. DISCUSSION

The Helon Model differs from previous preon models in that we have chosen to describe the properties of composite fermions and bosons not in terms of fundamental properties of the preons themselves (e.g. hypercolour), but in the interrelations between the preons (in essence extending the idea behind Harari and Shupe’s original explanation of colour charge to other quantities). We note once again that the helon model should, to be precise, not even be viewed as a preon model, but as a preon-inspired set of mathematical properties. The significance of this model is its extreme economy and extension of earlier ideas. The rishon model explained the number of leptons and quarks, the precise ratios of their electric charges, and the origin and nature of colour charge. The helon model does all this, but in addition it does away with the *ad hoc* assumption the permutations of preonic objects within a triplet are distinct, and explains why the ordering of should matter (leading to three distinct colour charges) in a natural way. A secondary consequence of this is to explain why charged fermions come in two varieties of helicity, while neutrinos come in only one. The helon model shows that baryon number (of quarks, not hadrons) and lepton number should be conserved in all weak interactions. We have derived the Gell-Mann–Nishijima relation from first principles using a simple counting argument. The helon model provides an explanation for the existence of generations, which predicts that neutrinos of a given generation will only interact directly with charged leptons of the same gen-

eration. All this is achieved using a much simpler set of “particles” and “interactions” than those of the rishon model - namely one type of fundamental object, a crossing operation, and a splitting/joining process.

Rather than being viewed as distinct types of processes, decays which violate strangeness, charm, bottomness and topness can be classified together as simply ‘generation-changing decays’ since S , C , B , and T have been demoted from their presumed roles as valid quantum numbers.

By representing the braided substructures of fermions and bosons as permutation matrices, we represented colour interactions as matrix addition. Interestingly the electroweak interactions behave as matrix multiplication. This point shall be taken up in more detail in further work, currently in preparation.

While the helon model explains many things, there are a number of issues it raises. Foremost among these is the question of just what physical process (if any) the twisting and braiding of helons represents. The correspondence between the topological structures of the helon model and the fermions and bosons of the standard model may represent a new way of interpreting states that occur in topological theories, such as M-theory. It was recently proposed that the helons may represent connection variables in the framework of Loop Quantum Gravity [11]. Development of this idea is reported in [12]. This represents the first step towards developing a dynamical theory of all interactions, particles, and spacetime itself, incorporating the helon model. Further investigation is required to see whether the helon model is consistent with all observed particle interactions, and whether it predicts interactions that are not observed. These and related issues are sure to determine the directions of future research.

VI. ACKNOWLEDGEMENTS

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 [7] Lewis Carroll, *Through the Looking Glass and what Alice found there* (1872)
 [8] This name was used in a slightly different context in the novel *Voyage from Yesteryear*, by James P. Hogan (1982)
 [9] See e.g. Kunio Murasugi, *Knot Theory and its Applications*, Birkhauser (1996), or any equivalent text on the

mathematical theory of knots and braids.
 [10] B. A. Robson, *Int. J. Mod. Phys.* **E11**, 555 (2002) and *Int. J. Mod. Phys.* **E13**, 999 (2004).
 [11] Lee Smolin, private correspondence.
 [12] S. O. Bilson-Thompson, F. Markopoulou, L. Smolin, [hep-th/0603022] (2006).
 [13] The twist of tweedles may be viewed as a spin in some abstract space, akin to isospin. We will not assume that this is the same as intrinsic angular momentum.
 [14] To be consistent with the GWS model we should probably say that these braids represent the W^0 and B . Conceptually there is little difference either way.