# A possible origin of the q=4/3 diquark

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**Abstract**

Between the new physics candidates proposed to explain the $t\bar{t}$ asymmetry measured in the Tevatron, there are some scalar diquarks with electric charge $+4/3$. This kind of diquark is also needed to classify all the scalars of the supersymmetric standard model, with three generations, under a global flavour symmetry.

One of the measurements that have caused some stir during the last run of the Tevatron has been the forward-backward asymmetry of top quark processes [1]. Between the different New Physics candidates that have been proposed (see e.g. [2]), some scalar "diquarks" in diverse multiplets are favoured, and particularly some isosinglets with charge 4/3.

While the hint is generically towards flavour models, here we want to show that when flavour is imposed not in the standard model fermions but in the scalar sector (squarks and sleptons) of the supersymetric SM, the candidate particles appear inside a very unique construction, that exhausts exactly for three generations with five light quarks. We explain this fact in the first section of the paper and then we proceed to speculate on other uses of a flavour symmetry inspired in composites.

## 1 Flavour in susy scalars

Independently of its physical interpretation, it is possible to use a flavour $SU(5)$ to classify the 24 sleptons contained in the SSM -when extended with right neutrinos-. This is done by taking this representation from $5 \otimes \bar{5} = 24 \oplus 1$ and then branching it down to $SU(3) \times SU(2)$.

$$24 = (1,1) + (3,1) + (2,3) + (2,\bar{3}) + (1,8) \tag{1}$$

Giving an electric charge $+2/3$ to the $SU(3)$ piece and $-1/3$ to $SU(2)$, it can be seen that we have got a sextet of charge $+1$, another opposite sextet of charge $-1$, and another twelve states of zero charge. The construction can be done for any odd number of generations, but it becomes specially elegant -and unique in some terms- when done for three.

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Now, we produce all the squarks from the same flavour group by taking the 15 of $\bar{5} \otimes \bar{5} = 15 \oplus 10$. With the same branching, it decomposes as

$$15 = (3, 1) + (2, 3) + (1, 6) \tag{2}$$

so that we get one sextet of charge -1/3 and another sextet of charge +2/3. We call this reproduction of the original charges a "supersymmetric Bootstrap", or *sBootstrap* for short, because it is possible to interpret the $SU(3)$ piece as coming from three particles similar to quarks $d, s, b$ and the $SU(2)$ piece similar to quarks $u, c$. If we pursue this interpretation, the uniqueness is more appealing: with more of three generations, not all of them are used in the flavour symmetry, and the number of extra particles makes the scheme a lot uglier, adding more exotic squarks and sleptons to the bag.

This symmetry was found some years ago in [10] and the uniqueness is discussed with more detail there, but even with three generations it had a severe handicap: the 15 multiplet has three extra scalars not in the standard model. Fortunately, they were different from the other scalars in the sense that, being a odd number, it was not possible to arrange them in Dirac supermultiplets; then this chirality was expected to be an advantage allowing either to eliminate them from the game board or to force them into the gauge sector (more on this later). But an acceptable, fully developed solution has not been found yet.

What is important for this brief letter is to notice what this $(3, 1)$ triplet is: the three scalars have charge +4/3 and can be assigned interactions as a scalar diquark. It is then the same kind of particle expected to solve the Tevatron asymmetry.

We can read this in two ways: on one direction, it could be said that an extra flavour symmetry for the scalar sector of SUSY predicts the need of 4/3 diquarks. On the reverse direction, it is possible that most of the models proposed to explain the asymmetry will exhibit explicitly a scalar flavour symmetry when super-symmetrized.

On the side of model builders, it may mean some extra work, because besides a colour triplet we also have a flavour triplet (naively, $uu$, $uc + cu$ and $cc$ like states). The degeneracy could be removed in some flavour-colour locking scheme, or it could be really there.

## 2 A mass formula?

Having stated the main point, this section is a long *Intermezzo*.

If SUSY has a flavour symmetry of its own, based on composites, some mass formula should be possible, and it could be that remnants of the mass formulae are still visible in the fermion sector even after SUSY breaking.

The most famous, given its precision, candidate for a mass formula in the lepton sector is Koide equation, found in a series of preon models for quarks and leptons formulated in the early eighties [5, 6, 7]. Really it predicted the mass of the tau lepton before the measurement of its current value, and still now it is exact inside one-sigma levels:

$$\frac{(\sqrt{m}_e + \sqrt{m}_\mu + \sqrt{m}_\tau)^2}{m_e + m_\mu + m_\tau} = \frac{3}{2} \tag{3}$$

What is happening in these models, roughly, is that we take the "square root" of the mass matrix and we decompose it as a multiple of the identity $U$ plus a traceless perturbation $V$, with the condition

$$Tr[U^2] - Tr[V^2] = 0 \tag{4}$$

Foot [9] suggested to read the formula more intuitively, as simply asking that the triple of square roots keeps an angle of 45 degrees with the triple $(1, 1, 1)$.

Besides its recent use to try to control the masses of neutrinos (see for instance [3, 8] and related references), the formula has got, as you can imagine, some discussion online, albeit surprisingly more formal and educated that some other popular topics. Perhaps the best result of the online discussion is the reformulation, by C. Brannen and others, in terms of a phase:

$$m_k = M(1 + \sqrt{2}\cos(2k\pi/3 + \delta_0))^2 \tag{5}$$

It is intriguing that for leptons M=313 MeV, typical of constituent quarks or of QCD diquark strings. But for quarks, a single triplet can not do all the job, nor thus a single $M$

From time to time, generalizations to the quark sector have been proposed, as well as some analysis of its validity under running of masses. But only recently it was suggested that having triplets with the same charge was too restrictive. Fits for the *uds* and *cbt* triplets were then found by [11] and confirmed by [4], where an extension to six quarks -which we will not discuss here- is also proposed.

Once the box is opened, it is interesting to try to produce all the masses from the two upper ones. We can solve (3) as

$$m_3(m_1, m_2) = \left( (\sqrt{m}_1 + \sqrt{m}_2) \left( 2 - \sqrt{3 + 6\frac{\sqrt{m_1 m_2}}{(\sqrt{m}_1 + \sqrt{m}_2)^2}} \right) \right)^2 \tag{6}$$

And then iterate from the current central values of top and bottom:

$$\begin{array}{lcl}
m_t & = & 172.9 \text{ GeV} \\
m_b & = & 4.19 \text{ GeV} \\
m_c(172.9, 4.19) & = & 1.356 \text{ GeV} \\
m_s(4.19, 1.356) & = & 92 \text{ MeV} \\
m_u(1.356, 0.092) & = & 0.036 \text{ MeV} \\
m_d(0.092, 0.000036) & = & 5.3 \text{ MeV}
\end{array}$$

As far as we know, there is not yet a theoretical justification for this ladder descent, as the original models have always worked with separate up-type and down-type quarks. But it is intriguing. It only fails for the up quark, and still it signals that its mass is smaller than $d$. Also you could notice that in one of the equations $\sqrt{m}_s$ has appeared as negative, while it is again positive in the next iteration. This gives some extra value to the use of the phase version (5) of the formula.

# 3 Towards technicolor

Finally, we wonder if, besides to explain the $t\bar{t}$ asymmetry, is it possible to exploit these diquarks in some Higgs-like scenario. The peculiar charge of these particles seems an impediment, but there is an interesting possibility: that some of this charge comes from $B - L$ in a non-chiral way. This is a typical feature of GUT models using a left-right symmetry.

From this perspective, the $(3, 1)$ diquarks should be seen as having some non-chiral interactions, providing colour and a piece of $Q_v = \frac{1}{2}(B-L) = \frac{1}{2}.\frac{2}{3} = \frac{1}{3}$ of electric charge, plus a chiral interaction providing the extant $Q_{ch} = +1$. If the condensation mechanism can get rid of the vector part of the interaction, our diquarks seem more alike the scalars of the gauge supermultiplets: color neutral and with integer electric charge. Looking B-L in a different foot that the rest of the symmetries is interesting because it also imply that we increase our disbelief in R-symmetry. You could have noticed that the scalars we are producing have a B-L value different in one unit respect to the fermions they are supposed to partner with.

Furthermore, color neutrality causes a degeneration, and the number of different states is now only three particles and the corresponding antiparticles. Under SUSY, the massless gauge supermultiplet needs to eat one chiral supermultiplet (with a fermion and two scalars) to get mass; one of the scalars becomes the extra degree of freedom of the W or Z, and the other surfaces as a Higgs scalar. Thus it is interesting that under color neutrality, and barring the degeneration -or controlling it with some flavour-colour locking, appropriate also to the discussion in the first section-, we get the number of scalars needed to make three chiral supermultiplets. Some work is being done to try to introduce these ingredients in an EWSB mechanism, but it is still in very early stages.

# References


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