On Color, Strings, and the SU(3) Model

Terry Bollinger
2022-08-24.22.37 EDT Wed

Comments on the PBS Space Time (Dr. Matt O'Dowd) post:
Why Isn't The Nucleus Ripped Apart?
https://youtu.be/y1px8hBl7zg

On Color

2022-08-24.22.37 EDT Wed

6:45 – Erratum. Instead of the red shown in the figure, the pion quark on the right should be anti-blue, that is, yellow. The three antiquark anti-colors are cyan (c or anti-red), magenta (m or anti-green), and yellow (y or anti-blue). Triplets of red, green, and blue are fine, and so are pro-anti pairs of the same color, but never only two of r-g-b for matter or two of c-m-y for antimatter.

Addendum: I almost skipped the rest of this video, but after returning, I was relieved to see that Matt got all of this right in later parts of the video, including the three c-m-y anti-colors. Still, it's always worth keeping this simple unbroken rule in mind: Ordinary ("pro") quarks carry only "pro" color charges r-g-b, while antiquarks carry only anti-color charges c-m-y.

On Strings

2022-08-24.23.16 EDT Wed

7:06 - Strings are real: These gluon flux tubes vibrate like quantized violin strings to give higher-mass, higher-spin versions of particles using the same quarks. These particle sets form nifty straight lines called Regge trajectories.

Unfortunately, when string theory first appeared, no one knew about quarks and flux tubes. They only saw patterns in the math without knowing that within the hadrons — systems of two or three quarks — there were actual vibrating strings composed of gluons, anchored at the ends by bola-like weights called quarks.

Alas, what ensued from this minor timing glitch was one of the worst financial and research catastrophes in science history, one that cost billions of dollars and sidetracked thousands of promising careers. A few folks took the math-only results discovered shortly before the flux tube and declared them proof that only the math mattered at sufficiently minute scales. This idea originated in something called S-matrix theory. From this math-first, physics-second premise, they further postulated that dramatically smaller math-first strings are the basis of gravity.

The main reason for making this dramatic conceptual leap was the presence of the number 2 in both sets of equations. As Matt notes later in this video (20:53), the temptation to pair topic-de-jour mysteries — back then, it was hadron spin-2 string-like vibrations and hypothetical spin-2 gravitons — can be emotionally satisfying but, without confirming evidence, also highly misleading. The folks who proposed superstrings missed the memo that the observed string vibrations are not abstract math but vibrations of flux tube strings terminated by quark end weights. Only these physical entities made of well-defined forces and particles made the string math work. Emboldened by their choice to ignore physical parts and focus only on the math of string vibrations, they created something called superstring theory.

At the time, trying to explain gravity this way was a decent research hypothesis, one worthy of perhaps about five papers. After that, someone should have pointed out that their idea lacked any equivalent to quarks and flux tubes of hadronic string theory. Instead, superstrings transformed into an abstractions-first, physics-never industry that consumed half a century of research, money, and careers. Superstring theory remains to this day as close to making zero lab-testable predictions as anything in the history of science.

This dismal outcome is, in general, what happens in physics whenever you disconnect math from laboratory results. If you think of math as a human-executed form of computer programming, you can see why such an approach equations-first, physics-second can quickly become as disconnected from reality as some top-end special effects CGI movie.

Eventually, the folks promoting this dropped the "super" and took over the old name of "strings" for their own. That's too bad since the original hadronic string theory was superb work, and it's a shame that its original meaning got sullied and forgotten in this fashion.

Finally, David Gross and Frank Wilczek are two of my all-time heroes in physics history for their perseverance in uncovering, formalizing, and promoting the importance of string-like behavior (asymptotic freedom) of quarks linked by flux tubes. They did so at a time when the abstract-math-first S-matrix model dominated the particle physics world, and it was not an easy thing. Ironically, Gross and Wilczek are just about the only people in the world who can genuinely claim to be string theorists since they are the ones who figured out the emphatically non-obvious and unexpected dynamics of the color force that makes hadronic strings possible. David Gross gives a delightful and fascinating review of their uphill battle against pure-math S-matrix abstraction in his 2005 Nobel Prize Lecture. You can read his story at this APS link:

https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.77.837

On the SU(3) Model

2022-08-25.15:22 EDT Thu

13:22 – "It is the eightfold way from earlier, and in fact, we can also use it for the eight colors of RGB, red, blue and green plus anti-red, anti-blue, anti-green — or as we know them better, cyan, yellow, and magenta, and then black and white at the center."

With 0 for black and 1 for white, here's a simple text version of Matt O'Dowd's figure:

```
    R — -B
  /       \
-G   0 1   G
  \       /
    B — -R
```

Since 0-black and 1-white are distinct, they have an additional feature separating them. The other feature, whatever it may be, can be viewed as a vertical separation with the 1 closer to the viewer and the 0 farther away. To get a feel for what that might mean for some actual particle quantity, let's imagine 1 is one unit of electron charge, and 0 is no electric charge. Using the small letter "o" for a "more distant" 0 gives this figure:

```
    R — -B
  /       \
-G   o 1   G
  \       /
    B — -R
```

But then you recall that RGB down quarks have ⅓ of the electric charge of an electron. And don't (-R,-G,-B) anti-up quarks have ⅔ of the electric charge of an electron? That suggests two more layers between the o and 1, which I'll show by putting the closer layer in uppercase and the farther one in lowercase:

```
    r — -B
  /       \
-G   o 1   g
  \       /
    b — -R
```

Given these four layers, we might just as well connect points closest to each other layers by adding a few more lines. It's easier to do that in pieces. Here are the nearest 3 layers:

```
    r — -B
  /  \    \
-G    1 — g
  \  /    /
    b — -R
```

And here are the farthest 3 layers:

```
    r — -B
  /     / \
-G — o     g
  \     \ /
    b — -R
```

Wow. That looks like the top and bottom of an ordinary cube balanced on one corner!

Which it is. Sheldon Glashow first pointed out this visualization of the SU(3) symmetry as an ordinary cube in 1980. However, I suspect from related papers that his colleague Abdus Salam came up with it. Glashow used this cube as a mnemonic for recalling the allowed charges of the fermions, though two such cubes are needed to show all 16 weak-aware fermion and anti-fermion types. You can find a prettier image of both Glashow cubes in a comment I made on an earlier PBS Space Time post:

https://sarxiv.org/apa.2022-08-05.0945.pdf

One historical oddity in how the Standard Model applies SU(3) is that it _suppresses_ the vertical (electric or T3 charge) axis by requiring the sum of three diagonals always to be zero. This zero-sum requirement flattens the cube-on-a-corner interpretation of SU(3) into a deflated hexagon. You can see this hexagon in any cube by placing one of its corners closer to your eye than the others (try it). The resulting hexagon is, of course, Gell-Mann's Eightfold Way.

Thus if your goal is merely to understand SU(3) and the Eightfold Way better, try putting some air back into whatever Eightfold Way hexagon you are viewing by looking for the missing vertical quantity. For the fermions that "air" is identical to the electric charges that always accompany color charges on all versions of quarks. Even the Standard Model sometimes occasionally acknowledges that remarkable data point by talking about "chromoelectric" or "color-electric" charge. And while "cube" doesn't sound as impressive as "SU(3)," using one when possible does make navigating those symmetries a lot easier.

2022-08-24.22.37 EDT Wed
PDF: https://sarxiv.org/apa.2022-08-24.2237.pdf