Delta Baryons, Isospin, and the Need for a New Mendeleev

Terry Bollinger, 2012-02-18

The Curiously Consistent Delta Baryons

A few days ago I asked a physics forum why the four spin 3/2 delta baryons have nearly identical masses and lifetimes, despite having different mixes of up and down quarks. The case of delta(+2) versus delta(-1) is especially striking, since delta(+2) is composed of 3 up quarks, u(+2/3), and the delta(-1) is composed of three down quarks, d(-1/3). Since the "rest mass" [1] of the up quark is roughly half that of the down quark, the simplest assumption would be that a delta(+2) should have about half the mass of a delta(-1). Yet to within a fraction of a percent, the delta(+2) has the same mass as a delta(-1). That is... odd! And also deeply fascinating, since it says that some kind of gears and wheels must be working behind the scenes to keep all the delta masses the same despite varying quark compositions.

The answer I got back was correct, precise, interesting, and mathematically lovely. Alas, it also reminded me of a joke about the pilot of an ultralight aircraft getting caught by a sudden deep fog and completely losing her bearings. Soon she finds herself in a dangerous cityscape where huge buildings loom suddenly out at her from the fog. She sees a man on top of one such building and in desperation yells out to him, "Where am I??" The man on top of the building yells back, "You're in an ultralight airplane!" Realizing immediately where she was, she regains her bearings and lands safely. How? She knew that the building had to be Microsoft headquarters, because their response to her desperate plea had been both factually correct and utterly useless.

Now in the case of the delta baryons, the answer I got back was that they all have about the same masses and lifetimes because of something called isospin symmetry. Not coincidentally, this is the same concept that allows the masses of spin 1/2 protons and neutrons to be very similar. Protons and neutrons, like the delta baryons, are composed only from up and down quarks, just with different spin orientations that add up to 1/2 instead of 3/2. The isospin symmetry is in turn part of a larger set of symmetries called Lie groups (pronounced “Lee”). I’ll just say that Lie groups have a lot to do with how things rotate in spaces with various numbers of dimensions.

So what’s wrong with that? After all, I not only got an answer, but one that was mathematically precise and directly related to both a historical prediction of new particles and a deeper understanding of the strong or color force. How can I possibly feel slighted by an answer that has had so much success at predicting and helping to verify new particles and concepts?

Easy: It didn’t answer my question. What I asked was *why* these remarkable coincidences of mass exist – that is, what are the underlying “gears and wheels” that enable the masses of these particles with very different charges and very different constituent particles nonetheless to have almost identical masses. The answer given by Lie groups boils down to saying that the particles are “symmetric” under certain rotation-like operations – think of Wheel of Fortune with the similar but numerically different wedges – and that in the case of the delta baryons, the symmetry is “almost exact,” meaning there is very little difference in their masses after you rotate in different electrical charges. That in turn is the same as saying “by selecting different mixes of quarks.”

Tautologies versus Symmetries

The problem is that such an answer is ultimately tautological. That is, it is a re-assertion of the premises of the original question, played back in a complicated mathematical form that makes it *sound* like an answer without really giving any new insight to the mass question. The most fundamental reason why the delta particles are all known to have the same mass is because *experimentally* they were found to all have about the same mass. No one predicted that – it just happened. The similarity of the masses of these particles then guided theorists to deduce, correctly, that the four delta baryons (and other groups of other particles) were closely related in some deeper way. That latter part worked out well, and it helped lead in time to some of the most fundamental concepts behind the Standard Model. But I would argue that while the resulting theories developed out of the clues provided by similarities of mass, they don't really address at any deep level why such mass similarities occur. You could in fact argue it the other way around: By leading to the extremely powerful and conceptually simpler quark model for composing heavy particles, the Standard Model ends up predicting that particles made entirely of either up or down quarks probably should have significantly different masses – a more strongly broken symmetry – than is actually seen in the four delta baryons. Given that the information learned about the delta baryons played a major role in the formulation of the Standard Model, that's a bit ironic.

Fundamental versus Coincidental Symmetries

A bit more pointedly: Despite their predictive power when used carefully, mathematical symmetries and concepts such as group theory are a great way to muddle things up royally if you are not careful in how you use them. If you are not careful, you can use group theory to transform simple and understandable relationships into multidimensional beasts whose notations so cryptic that it requires years of training just to read them. It can also make coincidental symmetries look more important than they really are. By a "coincidental" symmetry I just mean that the symmetry you see may be more a reflection of how you are doing your experiments than of nature itself.

A good example of the latter is the treatment in group theory of a property called strangeness, which was called that because it messed up a lot of early predictions in particle physics. We now know that strangeness is just a measure of how many strange quarks are in a particle. A strange quark is not much more than an overweight twin of the very common down quark. As it turns out, *every* fundamental point-like particle has three versions whose only difference is mass. For example, the electron also has a next-heavier version of itself called a muon.

Early experimenters and theorists did not know any of this, though. But early particle colliders were energetic enough to create lots of strange quarks, mostly because strange quarks are the lightest of the next generations fatter, higher-mass quark variations. Because these strange quarks are identical except in mass to down quarks, they could slip in and replace down quarks for any particle where a down quark would have been used. This considerably expanded the range of possible particles, and in doing so they also created a series of apparent symmetries that were based on a new property called "strangeness." By including strangeness in their descriptions of particle symmetries, theorists were able to predict new families of particles that were similar to earlier ones, but with varying degrees of symmetry.

Now it's important to point out that not only were these symmetries correct, they were extremely useful for predicting some critical new particles, in particular one called the omega(-1) that was composed entirely of down-like strange quarks. The omega(-1) is in fact the strange quark analog to the all-down-quarks delta(-1) particle that I mentioned earlier. So why complain about them?

Well, mostly because in retrospect they resulted in a false assumption that you can still see in older books and works on particle physics, which is the assumption that strangeness is some sort of deeper, more fundamental property of matter. It really isn't: It's just how many copies of the lightest of the fat quarks are in your particle. Given that there are a total of four such fat quarks (strange, charm, bottom, top), there is no *fundamental* reason for distinguishing strange any more than charm, bottom, or top. Or stated differently: The deeper symmetry must involve all six quark types, and should recognize that the archetypical quarks must always be the up and down quark, with the other four being just mass variants of these two. The symmetries found early on, such as the incomplete 3/2 spin baryon decuplet that led to the prediction of the omega(-1) baryon, were useful but badly incomplete, reflecting the limits of the particle colliders of the time as much as they reflected the symmetries of matter itself.

Groups also can be precise in ways that make them unnecessarily cryptic. I've already mentioned several examples of that by talking about interpreting symmetries in terms of recipes of properties, where "symmetry" often can also be described in less precise terms. These often take the form of a recipe in which features (e.g. electrical charge) can be added subject to some small set of rules, and where the components themselves may be versions of some simpler type. The quark model itself is a good example, since it allows essentially all possible heavy particles to be understood as combinations of two types of quarks, each of which also has two heavier versions. Such rule-based models are of course not as precise mathematically, but they can be very powerful tools both for understanding the associated math and for making predictions about what is or is not possible.

Mendeleev and Group Theory

If you've read this far and are still wondering why I even mentioned Mendeleev, the creator of the periodic table in chemistry, in my title, here's my real point:

The periodic table of chemistry is chock full of partial symmetries, and some of them are not that different from some of the symmetries found in particle physics. Thus for example Group 1 {H, Li, Na, K, Rb, Cs, Fr} of the periodic table is clearly a symmetry group, one with broken symmetries with respect to the continuous variables Mass and Electronegativity, but also with strong symmetry conservation with respect to the discrete symmetry OxidationState = +1. Lastly, there is a curiously sharp symmetry break for H, which has a dual OxidationState = {+1,-1}. Other symmetries exist across subgroups of the elements, such as in the way OxidationState increases across the table and exhibits other symmetries that if done correctly add up to either to 2 or 8. Other recursive symmetries exist, with approximate correlations to increasing atomic mass.

To the best of my knowledge, Mendeleev knew nothing or next to nothing about group theory. So instead of expressing all of the patterns he was finding in terms of mathematically precise groups with deep underlying connections to things like the theory of algebras, he made simple tables and tried to get similar things to end up adjacent to each other. Early particle physicists, who in many cases were inspired by Mendeleev, did in fact do similar things when they looked at variations across multiple variables to create groups such as singlets, doublets, triplets, octets, and decuplets.

The difference, though, is that Mendeleev never really took his work much beyond the table level. Instead, he just worked to put together a framework that made sense, documented the details of trends and other similarities across the table, and left it to later generations to decipher the inner gears and wheels behind the similarities.

In retrospect, that was probably a good thing. By organizing the data without adding much additional structure, Mendeleev produced a product ripe for much later developments in the theory of atoms and the quantum behavior. When the right ingredients finally arrived, they crystalized around the earlier

Periodic Table to form a profoundly insightful model that was full of gears and wheels. Much of this new structure could not have been theorized in Mendeleev's time in any case. The needed theoretical ideas did not yet exist, and they were so bizarre in their details that no amount of earlier speculation would have helped. Given that, the simplicity of Mendeleev's simple table and text representations likely made the later emergence of quantum-based chemistry easier, not harder.

But here's an interesting speculation: What if Mendeleev has also been an expert in group theory, and had insisted in phrasing everything he found in terms of higher-dimensional groups and concepts such as rotations in spaces defined by matrices and matrix operations?

In principle, he could have done just that. Shoot, someone could *still* do it if she had lots of spare time. The resulting theory would require some pretty big matrices, a lot of cryptic mathematical terminology, and likely a few items like tensor invariants tossed in for good measure. It would include a lot of symmetries, almost all of them broken to some degree, and very little explanation of why those breaks exist, but the net result would still describe the trends and behaviors of the periodic table. Instead of a piecemeal table, it would have the appearance of an integrated whole. That integrated package would contain a lot of mysteries and mysterious constants, but it would cover all of elemental chemistry in a single theory.

So my question is this: If a group-theory based periodic table had indeed been created in Mendeleev's time, and if because of its accuracy and all-inclusiveness it had been accepted by everyone as the Standard Chemical Elements Model, would it have helped or hurt the eventual emergence of quantum chemical theory a few decades later?

It's a real question, and I don't mean it to be trivial. But as a specialist in information, I am almost certain that representing the periodic table in terms of group theory would have done far more harm than good. Here's why: Compared to Mendeleev's more humble table-based presentation, I strongly suspect that an elaborate group-theory based version of the Periodic table would have created orders of magnitude more "theory noise" than the simpler table format he actually used.

Theory Noise

The concept of theory noise is important, since a theory is a form of communication. By saying that a theory is noisy, what I mean is that people trying to read and understand it will be forced to fill their heads with large numbers of concepts and terms that while not strictly incorrect are also not really required in order to convey the underlying message or predictions of that theory. Theory noise also includes needless redundancy, in which a single underlying idea ends up replicated and distorted into forms whose underlying commonality is no longer easy to discern.

Forced fitting of symmetries is one way that theory noise can arise. Forced fitting happens when a symmetry is made to fit the data by breaking it in ways that do not reflect any underlying reality. When this happens, the result can be a theory that actually distracts people away from the real causes of the underlying regularity. For example, the regularities of the Group 1 chemical elements did not receive a precise explanation until decades later, when new theories of atomic structure and quantum behavior were able to explain cycles of the periodic table in terms of the unusual stability of doublets and octets of electrons. If premature assignments of group symmetries had been made to describe Group 1 and other symmetries, the result easily could have been a false impression of knowledge that was not merited by the experimental data or the depth of theory – that is, it would have created theory noise.

When a theory has a high noise-to-content ratio, it becomes difficult to comprehend, and even adept users may have trouble pushing it forward. The noise begins to define the model, and users spend so much time dealing with that noise that they have few intellectual resources or options left to apply towards new, innovative ideas. Even worse, noise in a theory can severely reduce the odds that its users will recognize and cross-link commonalities within the model. The identification of such commonalities is typically one of the critical steps in making significant new theoretical progress.

Visually, a noisy theory can be pictured as a wall made of out of warped glass tiles. The tiles present viewers many different images of the reality on the other side, but at the same time provide no real insight into the rhyme or reason behind those details. Instead of being able to see the far side clearly and focusing on that, viewers end up spending huge amounts of time deciphering and understanding the many warped images that have been inserted into the light of sight. The ability to identify critical features of reality is largely lost, since viewers can no longer tell what is fundamental, what is a distorted image, and what is superfluous noise that has no relationship at all to the underlying reality.

The Mendeleevian Challenge

So three cheers for Mendeleev! He stuck to simplicity even as he worked to unravel one of the greatest mysteries of similarity and difference in all of scientific history.

And with that I would humbly like to challenge experts on the next level down from Mendeleev's work, that being the Standard Model of particle physics, to consider a bit of reconsideration. While there's no ambiguity that the Standard Model does remarkably well at capturing known particle physics, there is a separate question that needs to be addressed: Does the Standard Model convey its theoretical reality in a way that is simple, clear, lacking in noise, minimally redundant, and sufficiently fundamental?

Despite my huge respect for what the Standard Model has accomplished, on that question I would have to vote a solid no – and I suspect I'm far from the only one. Just this week a physicist who once worked at CERN noted to me that "the Standard Model describes everything and explains nothing." For almost forty years, particle theory has languished in a desert free of predictive challenges. This desert was created, ironically enough, by the long shadow of success emanating from the Standard Model. The lack of predictive challenges has left people to chase instead after vain philosophies, ideas that lack any real connection with experimentally predictive physics or traditional scientific criteria of theoretical success.

Transforming the Standard Model

I think physics has missed something. The Post-Mendeleevian quantum revolution was a sort of Deeper Insight phase that culminated in a brilliant and powerful new re-interpretation of the Periodic Table. This phase has simply never happened for the Standard Model. That's ironic, because both the old Period Table and the current Standard Model show clear signs of having deeper levels of gears and wheels, ones whose workings produce all sorts of cryptic almost-patterns and unexplained constants.

I think a huge factor in why the Standard Model has never reached its own Deeper Insight phase is because its early formulation leapt a bit too quickly into using crisp mathematical models that in many cases probably said more than they should have. Such models were well intended and worked well enough, but my strong suspicion is that they also created enough theory noise and redundancy to make further progress difficult. A new generation of physicists and mathematicians needs to reexamine the

Standard Model with an eye for what's really important, and with fervor for finding simpler ways to express what was captured directly from experiment.

Physics needs a new Mendeleev to go back over the standard model, someone more mathematical but with Mendeleev's same focus on simplicity of representation. But it also needs new revolutionaries who can peer deeper at the results any such simplification, looking for clues leading to the kind of Deeper Insights that transformed Mendeleev's work into modern quantum chemistry. Just as deciphering the structure of DNA rested as much on pulling on a couple of tiny and seemingly minor clues in the DNA data as it did on overall results, the Standard Model likely already has within its details the threads and hints of new, more powerful, and better performing models that will change physics in ways we just cannot predict.

Someone just needs to start looking for those threads, and start the process of pulling on them.

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[1] Rest mass is a somewhat fictional concept in the case of quarks, because quarks can only exist when bound to one or two other quarks via the strong force. That extremely powerful binding force causes the quarks always to be in motion.