A Realist Interpretation of QCD

Abstract

While the reality of quarks has been verified experimentally, we may say that the *concept* of gluons is more of a mathematical concept. In this paper, we explore the epistemological foundation of quantum chromodynamics. We do so by re-examining the concept of *partons*, which was introduced by Richard Feynman as a generic term for pointlike constituents of matter. We examine whether or not the concept of a colorless, flavorless and zero-charge parton – onto which we can then load the various properties that are necessary to explain reality – might work.

The conclusion is that the parton model may offer sufficient degrees of freedom to model what the quark-gluon model is modelling. In fact, we suggest the idea of quarks and gluons might be a bit like the 19th century *aether* theory: we don't need it. The underlying question is, of course, much more fundamental: do we need quantum field theory?

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Introduction

Quark theory suggests the strong charge comes in three colors. We might also have referred to these colors as flavors but that term has been reserved for something else (different *types* of quarks) so we can't use that for the strong charge. The point is: the strong charge is *not* binary. In other words, it is *not* like the electric charge: plus or minus one unit. We think of protons and neutrons as RGB color white: equal amounts of red, green and blue. If you're into programming, it's hex code #FFFFFF or decimal code rgb(255,255,255). The colors are pure: we can only have white: rgb(255,250,250) makes for snow. That color is *off*. Only a little bit, but it's off. I mean: *not* possible. Forget about it.

According to quark theory, you can also make pure white by mixing color and anti-color: green and anti-green also makes white, and so does red and anti-red, and blue and anti-blue. So you might think we have five varieties of particles: (1) red/blue/green, (2) anti-red/anti-blue/anti-green, (3) green/anti-green, (4) blue/anti-blue, and (5) red/anti-red. But six varieties is a bit too much, perhaps. Let's think.

We have protons and neutrons: they combine red, blue and green. We also have their anti-matter counterparts: anti-protons and anti-neutrons consist of anti-red, anti-blue and anti-green. Then we have mesons. Mesons have a color and an anti-color. Pions are examples of mesons. We'll say more about them later. For the time being, we should think of two types of matter only:

1. Baryons (e.g. protons and neutrons): they consist of three colors (or three anti-colors).
2. Mesons (e.g. pions): they consist of a color and an anti-color.

What's *matter*? Good question. We do *not* think of photons as matter: they are the particles of light, but they're not material. We think of them as an electromagnetic oscillation traveling through space.[1] What about electrons? Electrons don't partake in the strong force – so they don't carry any color charge – but they are, obviously, matter too. Leptons, in general, are. So we think of matter – or the elementary *constituents* of matter – as carrying electric charge.

Let us think about the use of the *anti*-prefix in this context: it should make you think of anti-*matter*. Anti-matter is just plain matter with an opposite *electric* charge. Hence, anti-red, anti-blue and anti-green may just refer to red, blue and green 'things' with the opposite *electric* charge. There is no such thing as an opposite *strong* charge. If you want to think of opposites, you should, perhaps, think of blue *and* green as the opposite*s* (plural!) of red. Likewise, you can think of blue and red as the opposites of green. Hence, we may wonder if the concept of an *anti*-color is actually necessary.

Let us try to do without. Instead of a quark-gluon model, we'll try to develop a *parton* model. The term parton was coined by Richard Feynman and it, therefore, has a rather specific historic meaning. We will just borrow his term here to refer to some pointlike *constituent* of matter. Note that pointlike does *not*

[1] See: Jean Louis Van Belle, *A Classical Quantum Theory of Light*, 13 June 2019 (http://vixra.org/abs/1906.0200).

necessarily it has no dimension whatsoever. On the contrary, we think the assumption it occupies some (very tiny) space is essential. Think of our explanation of the anomalous magnetic moment here![2]

So let us start building our parton model. We can do it by combining electric and color charges. We get the following combinations:

charge and color	red	green	blue
+2/3	+2/3	**+2/3**	**+2/3**
–1/2	–1/3	**–1/3**	**–1/3**
–2/3	–2/3	**–2/3**	**–2/3**
+1/2	+1/3	**+1/3**	**+1/3**

So we have 12 partons. That looks like a lot. Quark theory has only two. For its first generation, that is. We'll say more about the second and third generation later. Indeed, Gell-Mann – the inventor of quark theory – apparently thought *something* should carry the *electric* charge, and he defined the *up* and *down* quark. I prefer the *u* and *d* abbreviation because up and down makes you think of spin, and the name of these quarks has nothing to do with that: they're both spin-½ particles and the spin of both the *u* and the *d* quark can be up or down.

Let us think about why these quarks are different from our partons. The up and down quark do not carry the color charge. To be precise, they actually do but they are thought of swapping colors all of the time. That's a bit weird but it is what it is. You might think the quark model is more economical because we avoid having to define six particles (and their anti-particles, of course). Two quarks (and two anti-quarks) is better, isn't it?

I am not so sure because we have nine different gluons:

gluons	red		green		blue	
anti-red	**red**	**anti-red**	**green**	**anti-red**	**blue**	**anti-red**
anti-green	**red**	**anti-green**	**green**	**anti-green**	**blue**	**anti-green**
anti-blue	**red**	**anti-blue**	**green**	**anti-blue**	**blue**	**anti-blue**

Hence, what I will refer to as the *quark-gluon* model doesn't come with any simplification:

1. The quark-gluon model gives us two quarks, two anti-quarks and nine gluons, so that adds up to 13 different objects.
2. If we just combine the possible electric charges ($\pm 2/3$ and $\pm 1/3$) and the possible color charges (red, green and blue), we only have 12 objects. I'll refer to this as the parton model.

Note that our parton model has no need for anti-colors: the anti refers to the opposite *electric* charge, so we capture that in the possible electric charges, of which we have four. Also note that, when you read up on quark theory, physicists will tell you there are only eight *independent* color-anticolor combinations, so instead of 13 objects, we'd also have 12.

[2] See: Jean Louis Van Belle, *The Anomalous Magnetic Moment: Classical Calculations*, 11 June 2019 (http://vixra.org/abs/1906.0007).

Twelve or thirteen. It doesn't matter all that much. I find the quark-gluon model weird. Something inside of me tells me physicists prefer the quark-gluon model because it allows them to think of stuff using their *pet* theory: quantum field theory. If you read anything of what I wrote on QED and QCD so far, you will understand that I am very hesitant to think in terms of elementary particles exchanging *virtual* particles as part of their interactions. I don't see why we need the concept in QED, and so I need to be convinced of why we would need it in QCD.

You'll say: the *up* and *down* quarks have a different (bare) mass, so that's probably the reason why we need these two quarks. I'd say: if we have different charges (+2/3 and –1/3 are both red but they are not the same) then we may think of some 'mass without mass' theory – some kind of *Zitterbewegung* idea for the nucleus – that *gives* us this mass difference.

I am *not* saying this is going to be easy. I am just saying that, in my search for a *realist* interpretation of quantum mechanics, I am *imagining* it can be done, *somehow*. We don't need the concept of quarks for that.

Accounting for variety with quantum numbers

We have a lot of quantum numbers in QCD. The ones we know: spin and electric charge, for example. But also quite a few that sound weird. The flavor quantum numbers: isospin (I_3), charm (C), strangeness (S, not to be confused with spin), topness (T), and bottomness (B'). The accent (') in the symbol for the bottomness (B') is to distinguish it from yet another quantum number: the baryon number B. The baryon number is 1/3 for all quarks. It's something you need in the chemistry equations of QCD.

I am not joking: QCD equations are like chemistry. Instead of keeping track of atoms (or ions) and electric charges, you keep track of quarks, spin and charges. But do we need quarks? Can't we just keep track of spin and (electric) charge? And energy, of course!

I think that should work for all *stable* configurations—for all *real* particles, that is. Here we need to be precise in our language. How *real* is a particle that exists only for like 26 nanoseconds only? In case you wonder, this number – 26×10^{-9} seconds – is the mean lifetime of a (charged) pion.

I prefer to refer to those particles as resonances rather than particles. A particle is a permanent fixture: it doesn't decay. In contrast, a resonance dies out. That's where the concept of a mean lifetime comes in. What about free neutrons? They have a mean lifetime of about 881.5 ± 1.5 seconds, so that's about 14 minutes and 41.5 seconds (the concept of the half-life of this process (611 ± 1 s) is somewhat different but the order of magnitude is the same). Are they stable? No. They are *quite* stable, but all is relative. They decay. Protons don't. As far as we know, at least: we haven't *observed* proton decay, so we assume protons are as stable as electrons.

Why are neutrons stable in a nucleus but not in free space? We think it's the Planck-Einstein relation: two protons, two neutrons and two electrons – a helium atom, in other words – are stable because all of the angular momenta in the *oscillation* add up to (some multiple of) Planck's (reduced) quantum of action. The angular momentum of a neutron in free space does not, so it has to fall apart in a (stable) proton and a (stable) electron – and then a neutrino which carries the remainder of the energy. Let's jot it down:

$$\mathrm{n}^0 \rightarrow \mathrm{p}^+ + \mathrm{e}^- + \bar{\nu}_\mathrm{e}^0$$

Let's think about energy first. The neutron's energy is about 939,565,420 eV. The proton energy is about 938,272,088 eV. The difference is 1,293,332 eV. That's almost 1.3 MeV.[3] The electron energy gives us close to 0.511 MeV of that difference – so that's only 40% – but its *kinetic* energy can make up for a lot of the remainder! We then have the neutrino to provide the change—the Euro *cents*, so to speak.

Let's say something about neutrinos here. They are neutral, so what's an *anti*-neutrino? Well… The specialists in the matter say they have no idea and that a neutrino and an anti-neutrino might well be one and the same thing.[4] Hence, we might as well write ν_e. No mystery there—not for me, at least. Or not here and not right now, I should say—because neutrinos are a bit mysterious. Did you know there is a neutrino theory of light?

You may like to think of them as change. Indeed, when you talk money, you need big and small denominations—banknotes and coins. However, that role can be played by photons. Gamma-ray photons – produced by radioactive decay – can have energies with a MeV order of magnitude. So they will do when one needs change or coins. So there's more to it: you see neutrinos whenever there is radioactive decay. Hence, we should associate them with the weak force but *how exactly* is a bit of a mystery. Let's get back to spin and charge. The equation above conserves angular momentum (spin) and electric charge. We're not worried about the color here. Should we be worried? I don't think so: the proton consists of three colors too, so we're fine.

We could look at an equation that looks like the reverse of the equation above – electron capture by a proton – but we will let you do that as an exercise. Let's have a look at pions—just to check if we need that color business there.

Pions can have positive, negative or no charge: we have π^+, π^- and π^0 particles, or *resonances*, we should say—because they decay so fast. Pions are often thought of as the carrier particles of the strong force – the stuff that Yukawa wanted to predict – but, as mentioned before, I think QCD still has to make the case for the need of a carrier particle. Let us just look at them as resonances: some temporary arrangement that quickly decays into something more stable.

The π^+ and π^- particles have a slightly higher energy than the π^0 particle but, more importantly, their mean lifetime is much more measurable: it's about 26×10^{-9} seconds. In contrast, the mean lifetime of the π^0 particle is measured as something like 84×10^{-18} seconds. The difference between nanoseconds (10^{-9} seconds) and attoseconds (10^{-18} seconds) is 10 to the power 9, so that's a *billion*. The disintegration process is also *very* different:

1. The π^+ and π^- resonances decay into a *muon* (positive or negative) and a *muon neutrino*.
2. The π^0 resonance just leaves two photons.[5]

[3] CODATA data gives a standard error in the measurements that is equal to 0.46 eV. Hence, the measurements are pretty precise.
[4] See the various articles on neutrinos on Fermi National Accelerator Laboratory (FNAL), such as, for example, this one: https://neutrinos.fnal.gov/mysteries/majorana-or-dirac/. The common explanation is that neutrinos and anti-neutrinos have opposite spin but that's nonsensical: we can very well imagine one and the same particle with two spin numbers.
[5] We will quality this statement in a minute.

Muons are unstable as well, but their mean lifetime is measured in *micro*-seconds (10^{-6} seconds). Guess what? They decay into an electron or a positron (depending on their charge) and neutrinos. Let's write it down:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \ \rightarrow e^+ + \nu_e + \nu_\mu$$

Just change the signs for the π^- decay.[6] What about the energy equation? The energy of charged pions is about 139.57 MeV. That's a sizable chunk of money—at the nuclear level, that is. To put that number into perspective: it's about 15% of the energy of the proton. Hence, if it *would be* some kind of 'exchange particle', then it's pretty heavy. We'll come back to why we are so skeptic as to its actual role—I mean the *italics* in the preceding sentence. The (rest) energy of a muon is about 105.66 MeV but, just like with neutron decay, we must assume kinetic energy explains most of the missing energy in this story.

As for the next step – a step *down* from the muon to the electron (or positron, in this case) – we get another *muon* neutrino. What's the difference between an *electron* neutrino (ν_e) and a *muon* neutrino (ν_μ)? One is heavier than the other. That's all. What's *heavier*? More energy. That's all. But that's a lot—obviously!

That's the interesting thing with these flavors or generations of particles. The next flavor – or next generation – comes with higher energy, but shorter lifetime. In that regard, we should remind ourselves that theorists and experimentalists also think *tau*-leptons are, *somehow*, quite real—even if their mean lifetime is only about 29×10^{-12} s. *Pico*-seconds.

You might think there is some easy relation between decay times and energies but that's not the case. The table below lists energy and mean lifetime for electrons, muons, pions and tau particles. In the third and fourth column, we multiply both and then express it in terms of Planck's quantum of action.

	energy (eV)	lifetime (s)	E·t (eV·s)	E·t/h
Electron (e)	5.11E+05	∞	∞	∞
Muon (μ)	1.06E+08	2.20E-06	2.32E+02	5.61E+16
Pion (π)	1.40E+08	2.60E-08	3.63E+00	8.77E+14
Tau (τ)	1.78E+09	2.90E-13	5.15E-04	1.25E+11

It shows that the pion and the muon have comparable energies – the order of magnitude is the same – but their lifetimes are quite different, although 2.2 microseconds and 26 nanoseconds differ by a factor that's not too large: to be precise, they differ by a factor that's equal to 84.5. In contrast, the energy of the tau particle is about 16.8 times that of a muon, but its lifetime is about 7.5 *million* times shorter.

If we believe the energy of a particle reflects some kind of elementary cycle, then the eternal lifetime of the electron ensures we can associate it with an infinite amount of physical action. In contrast, because of its very short lifetime, a tau particle can*not* pack a lot of physical action—expressed in eV·s or as a

[6] The second step in the decay makes abstraction of the muon neutrino that was produced in the first step of the decay process.

multiple of Planck's quantum of action. We referred to these unstable particles as *resonances*, but *transient* particles is probably a more appropriate term: they're just like an oscillation that dies out.

Three-body problems, oscillators and symmetries

The ternary structure of the strong force is a bit daunting. We know we don't have an analytical solution for the three-body problem, so how can we hope to make sense of the strong force?

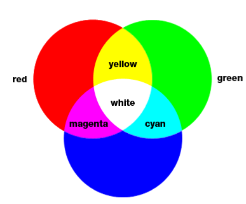
We should make two remarks here. First, there is a very special case of the three-body problem that is referred to as the *elastic* 3-body problem. I'll refer you to an animated *gif*-file – it's one of those animations that is worth a zillion words[7] – that shows starting conditions for the gravitational 3-body problem usually result in chaos. In contrast, there is no such problem (no chaos) for an elastic three-body problem. So we may want to think along those lines.

We noted above that it looks like there is no *conceptual* difference between thinking of a red, blue or green quark and its anti-quark (an anti-red, anti-blue or anti-green quark with opposite *electric* charge) or – a bit simpler – to think of some *parton* with three possible colors and four possible charges. We prefer the parton approach. Why? What's in a name? We just think the concept of some parton that comes in 12 possible varieties (three colors and four charges) separates stuff better.

So now we want to make particles of partons. We need to introduce some rules, of course. One of them is that the charges have to add up to the elementary charge (+1 or –1) or – for neutral particles – have to equal zero. That's where the *anti*-color in the quark-gluon model comes in, but we don't want to think in terms of anti-colors. The electric charge rule will do. What about our white-color rule? We can drop that for the time being. If we allow red to combine with itself and with blue and green, we get a matrix. To be precise, the strong force may be different for red and red, red and green, and red and blue, so we can put some coefficients in.

	red	**green**	**blue**
red	$S_{\text{red-red}}$	$S_{\text{red-green}} = S_{\text{green-red}}$	$S_{\text{red-blue}} = S_{\text{blue-red}}$
green	$S_{\text{green-red}} = S_{\text{red-green}}$	$S_{\text{green-green}}$	$S_{\text{green-blue}} = S_{\text{blue-green}}$
blue	$S_{\text{blue-red}} = S_{\text{red-blue}}$	$S_{\text{blue-green}} = S_{\text{green-blue}}$	$S_{\text{blue-blue}}$

We have nine coefficients but only six of them will be independent. This is actually where the color mixing picture comes to mind: red and blue makes purple (or, to be precise, magenta), red and green makes yellow, and green and blue makes blue-green (which is also referred to as cyan). So we have three primary colors and three mixed colors.



[7] See: https://commons.wikimedia.org/wiki/File:3bodyproblem.gif#/media/File:3bodyproblem.gif

If you know anything about QCD, the matrix may make you think of the Cabibbo–Kobayashi–Maskawa matrix, but it's got nothing to do with it: that matrix gives you the probability (or amplitude) for the *flavor* (*u*, *d*, *c*, *s*, *t*, *b*) to change into another. As for now, we don't think we need quark *flavors* to explain transient particles. We have enough degrees of freedom here.

We should probably remind ourselves of the properties of a symmetric matrix here: An *n*-by-*n* symmetric matrix will have *n* eigenvalues, and we can then find a set of *n* eigenvectors – one for each eigenvalue – that are mutually orthogonal. The matrix here is a 3-by-3 matrix: something inside of me tells me this should explain the three *generations* of matter in the Standard Model.

The electric charge rule – the electric charge has to add up to +1, 0 or −1 – should then explain the rest. The concepts of quarks, gluons or flavors sounds a bit like the *aether* theory. The philosophical concept of a colorless, flavorless and zero-charge parton – onto which we can then load the various properties we need to explain reality – may work just as well.

Accounting for variety by combining charges

Our partons come in 12 varieties but they will only make a meson together if the total charge adds up to 0 or ±1. That works in half of the cases, so that's eight of sixteen possibilities. Of course, we can't distinguish the A and B combination from the B and A combination, so we only have four possibilities, as shown below.

A and B	-0.67	-0.33	0.33	0.67
-0.67	-1.33	-1.00	-0.33	0.00
-0.33	-1.00	-0.67	0.00	0.33
0.33	-0.33	0.00	0.67	1.00
0.67	0.00	0.33	1.00	1.33

Both particles can come in one of three colors, so we have 3×4 = 12 possible combinations. You may think that is *not* enough to explain the huge variety in mesons: the Particle Data Group[8] lists about 200 of them. Yes. *Two hundred*. Maybe there are more. QCD has enough weird quantum numbers (not only the electric and color charge but also isospin, flavor and other numbers (e.g. the baryon number). It just shows that QCD is just an *ad hoc* theory: physicists invented a lot of numbers and then found the particles they wanted to find.

I am being too harsh here, but there is a grain of truth in it: quantum numbers such as *strangeness*, *charm*, *beauty* (or *bottomness*) don't give any *real* explanation. You'll say: yes – but you somehow need to explain the variety, so how do you do that?

In any *realist* interpretation of QCD, a charge will be associated with spin and orbital angular momentum. As we've argued in our classical explanation of the anomalous magnetic moment of an electron, these two may also be coupled *classically* – which is why we think the anomalous magnetic moment is not anomalous at all.[9] Hence, the four possible electric charges (±1/3 and ±2/3) may have

[8] The Particle Data Group keeps track of what is found. The latest list of mesons can be found on this link: http://pdg.lbl.gov/2019/tables/rpp2019-sum-mesons.pdf.

[9] See the reference above.

their spin up or down, so that multiplies the 12 varieties of our parton by 2. But, you are right, 24 combinations is not enough. We need other *variables*. Are there are any other candidates than *strangeness*, *charm* or *beauty*? Yes. Some kind of classical coupling between the spin and the orbital angular momentum multiplies the possibilities once more. If we assume – rather conservatively – that the orbital angular momentum may also take two values only, then we can multiply the possibilities by four (two spin-only numbers combined with two orbital angular quantum numbers).

But that's electric charge only. If we believe the color charge is something real – and I mean: more *real* than the hypothetical quarks or gluons that carry it – then we may imagine something similar to the electric current and the magnetic moment: we can imagine a *color* current, and a *color* moment. I must be joking, right? I am not. *Strange*, *charm* and *beauty* sound like characters out of a story for kids, so I think color current and color moment may be more rational and, therefore, more scientific. This color moment may be binary, ternary or *n*-nary (and, yes, I invented a new word here) and – importantly – it will be binary, ternary or *n*-nary for *each color*. And we may also distinguish between a spin-only and an angular color moment, so even if it's binary (like the *up* or *down* of the magnetic moment of an electron), then we can multiply the possibilities by nine (three spin-only numbers combined with six orbital color momentum numbers).

Twelve times four times nine makes 432. That's variety enough, I guess. 😉

What about baryons? We can follow the same reasoning: we have 12 varieties of partons that can combine. Of course, we should avoid double- or, in this case, triple-counting, so we have $12^3/3 = 576$ possibilities. We don't even need to think of color spin and color moments: that's plenty to cover the current list of baryons or baryonic resonances.

Conclusions

While the reality of quarks has been verified experimentally, we may say that the *concept* of gluons is more of a mathematical concept. In this paper, we explored the epistemological foundation of quantum chromodynamics. We did so by re-examining the concept of *partons*, which was introduced by Richard Feynman as a generic term for pointlike constituents of matter. We examined whether or not the concept of a colorless, flavorless and zero-charge parton – onto which we can then load the various properties we need to explain reality – might work.

The conclusion is that the parton model may offer sufficient degrees of freedom to model what the quark-gluon model is modelling. In fact, we suggest the idea of quarks and gluons might be a bit like the 19th century *aether* theory: we don't need it.

The underlying question is, of course, much more fundamental: do we need quantum field theory?

Jean Louis Van Belle, 2 July 2019