Could Charge and Mass be Universal Properties?

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October 26, 2017

Abstract

There is a tradition in contemporary analytic metaphysics of looking to fundamental particle physics for an accurate list of universal properties. The central candidates for such properties are electric charge, color charge, and mass. Tim Maudlin has recently argued against a number of metaphysical theories within this tradition (Aristotelian and Platonic theories of universal properties, trope theory, the theory of natural sets, etc.) on the grounds that the general formalism of our current best fundamental physics–i.e., fiber bundles–precludes the notion of universal property used in these metaphysical theories. Consequently, Maudlin calls for a "wholesale revision" of the theory of universals. This paper argues, contra Maudlin, that the fiber bundle formalism does allow for the possibility of some universal properties, and thus a wholesale revision of this metaphysical theory is not yet warranted.

1 Introduction

There is a tradition in contemporary metaphysics of looking to particle physics to inform our understanding of fundamental ontology. For instance, Armstrong endorses an "*a posteriori* or scientific realism" about properties and relations, where the properties of particle physics are taken to at least approximate the true ontology of the world.[1] In this vein, Lewis lists mass, electric charge, and the colors and flavors of quarks as his prime examples of "perfectly natural" properties.[2] The metaphysician following Armstrong and Lewis in this tradition concedes that perhaps she cannot be a realist about all properties, but she invokes physics to

[1] "If we combine an *a posteriori* or scientific realism about properties (and relations) with the speculative but attractive thesis of physicalism, then we shall look to physics, the most mature science of all, for *our best predicates so far*. Physics. . . shows promise of giving an explanatory account of the workings of the whole space-time realm, and thus, perhaps, the whole of being. And it shows promise of doing this in terms of a quite restricted range of fundamental properties and relations." ([Armstrong, 1997], p. 167.)

[2] See [Lewis, 1997] p. 179. Lewis uses this exact list numerous times. Cf. [Lewis, 1997] p. 186 (footnote 6) as well as [Lewis, 1986] p. 14, 67 (footnote 47), and 178.

warrant her realism about some properties—including mass, charge, and the like. Moreover, once particle physics has given her an accurate list of these most basic properties, the rest of her metaphysical theory can be built up from there.

Tim Maudlin argues against this approach to traditional metaphysics on the grounds that the most general notion of a universal property is precluded by the mathematical structure of fundamental physical theories. While Lewis and Armstrong look to fundamental physics to provide an accurate list of (universal) properties, Maudlin thinks that fundamental physics instead provides good reason to think that there are no such properties. So we have the following main question.

The Main Question: are properties like mass, electric charge, color charge, etc. candidates to be universal properties?

Maudlin thinks that his argument settles the question in the negative. His argument proceeds by taking the color charge of quarks–one property off of Lewis's list—as his primary example. Maudlin intends for his argument to generalize from the specific case of color charge to the other properties from Lewis's list, so that he can conclude that there are *no* universal properties. He concludes that, because he has "eliminated" all of the properties from Lewis's list, "a wholesale revision" of that traditional picture of universal properties is in order.

This paper aims to show that Maudlin's argument does *not* settle the main question.[3] (It is beyond the scope of this paper to settle the question one way or another.) While Maudlin's argument succeeds against one notion of color charge, there are other properties for which it either fails or does not apply. This is not to say that Lewis and Armstrong are free to continue to think of every property from particle physics exemplifying just one notion of fundamental property in some univocal way. Indeed, as we shall see, there are physically

[3]It should be noted that Maudlin's argument against universal properties is presented as a part of a much larger project concerned with Lewis's full metaphysical picture of Humean supervenience. My criticism of Maudlin's argument against universal properties is not intended to address that larger project. Indeed, I think that Maudlin could retain much of what he wants to say against Humean supervenience while also accepting universal properties.

important senses in which electric charge is not at all like color charge, and yet both are fundamental properties. There is more than one way to be a fundamental property.

The remainder of the paper is structured as follows. Section 2 reviews the traditional metaphysical approach to scientific realism about properties as presented by Lewis and Armstrong, and it then clarifies Maudlin's argument against it. The import of this section is that we arrive at Maudlin's criterion for settling the Main Question. Then in section 3 I argue that Maudlin's argument against the existence of universal properties is successful on only one notion of color charge. There are at least two other physically operative notions of color charge *qua* property that a particle might have, on which Maudlin's argument fails. In section 4, I show that Maudlin's argument does not generalize to the properties of electric charge and mass. Concluding remarks are given, and a few metaphysical morals drawn, in section 5.

2 Maudlin's Argument

Maudlin's argument is aimed against a large swath of metaphysical theories of fundamental ontology, including trope theory, Lewis's theory of sparse properties, theories of primitive naturalness, and all variants of universal properties. The argument is meant to be so general that even the radical differences between Aristotelian and Platonic universals are irrelevant ([Maudlin, 2007] p. 80, note 1). Maudlin chooses to take universal properties as representative. In concluding that there are no universal properties, he means to also conclude that there are no tropes, no primitively natural sets, etc. I will here follow Maudlin in using the term 'universal property' as representative of this larger collection of notions of fundamental properties.

Since Maudlin wants to think of properties at such a general level, it is difficult to see what exactly it would take for a given property to be a universal. But, at the very least, any good universal property should be able to 'carve nature at the joints', an image that originates with Plato. In the *Phaedrus*, Socrates says that it is a principle of good discourse that divisions of species be made "according to the natural formation, where the joint is, not breaking any part as a bad carver might" (265e). Lewis and Armstrong both make allusions to this image. Lewis says this work of carving nature at the joints is done by what he calls "sparse"[4] properties, which he also calls "perfectly natural" properties.

> Sharing of [sparse properties] makes for qualitative similarity, they carve at the joints, they are intrinsic, they are highly specific, the set of their instances are *ipso facto* not entirely miscellaneous, there are only just enough of them to characterize things completely and without redundancy. ([Lewis, 1997] p. 178)[5]

Moreover, both Lewis and Armstrong take it that fundamental physics is the best place to look for those properties that will delineate the natural joints. Lewis says that "physics has undertaken...an inventory of the *sparse* properties of this-worldly things" ([Lewis, 1997], p. 178). Similarly, Armstrong cites the mature sciences as the best place to look for the most fundamental properties:

> How do we determine what these ontological properties are? ... With difficulty... But in the present age we take ourselves to have advanced...and to have sciences that we speak of as 'mature'. There we will find the predicates that constitute our most educated guess about what are the true properties and relations. Property-realism. . . should be an *a posteriori*, a scientific, realism. ([Armstrong, 1997] p. 166-167)

And it is the mature science of physics that shows the most promise of providing the metaphysician with an accurate short list of fundamental properties and relations. Again, Lewis explicitly lists mass, flavor, electric charge, and quark color charge as examples of "perfectly natural" properties.

[4]Sparse, that is, in contrast to the 'abundant' properties. A set of things sharing any given abundant property may be as miscellaneous and arbitrary as you please. For example, the union of the set of *things that are in my house* with the set of *penguins in Antarctica with spots on their left wings* shares one of these abundant properties. Exercising a little imagination to find other such arbitrary unions quickly shows that such properties truly are abundant. See [Lewis, 1986] p. 59 ff.

[5]Cf. Armstrong: "And here, I think, we are led on to Plato's marvelous image of carving the beast (the great beast of reality) at the joints. The carving may be more or less precise, so we reach predicates that are of greater and greater theoretical value, predicates more and more fit to appear in the formulations of an exact science." ([Armstrong, 1997], p. 166)

Maudlin argues that, given the mathematical formalism of contemporary fundamental physics, it is not possible to interpret the properties on Lewis's list as universal properties. The key for Maudlin's argument is a criterion that he calls "metaphysical purity." If, for a given property, it can be shown that the property is not metaphysically pure, then the property cannot be a universal. He gives the following necessary condition for metaphysical purity:

> [I]f a relation is metaphysically pure, then it is at least *possible* that the relation be instantiated in a world in which only the relata of the relation exist...if [this condition] fails, then the condition for the holding of the relation must make implicit reference to items other than the relata, so the relation is not just a matter of how the relata directly stand to each other. (p. 86) [Emphasis in the original]

Similarly, a metaphysically pure property is such that it is at least possible that it be instantiated in a world inhabited by only one thing with said property.

Maudlin does not give any examples of metaphysically pure relations or properties, and, while this may be frustrating to his readers, it is not surprising. He intends to argue that there are no such relations or properties in nature, so it would be misleading to give any examples. Presumably, we may take, for example, *having the same electric charge* and *having the same mass* as candidates for metaphysically pure internal relations. Imagine a world with just two electrons in it. Lewis and Armstrong would (presumably) want to say that those two electrons instantiate both of these relations, and moreover that they do so in virtue of sharing the metaphysically pure properties *having electric charge -1* and *having mass .51 MeV*.[6] These are the sorts of properties that are supposed to 'carve' at the natural joints. Maudlin intends to show that, in light of how these properties are treated mathematically in fundamental physics, *none* of them can be instantiated in a metaphysically pure way.

Maudlin does not explain why he thinks this criterion of metaphysical purity is a good test for whether or not a given property can be a universal. For the sake of argument, I will

[6]There are, to be sure, substantive metaphysical debates about just *how* this sharing of a fundamental property works, with the three most prominent contenders being trope theory, primitive naturalness, and universals. Maudlin's argument is intended to refute all of these at a very general level.

assume here that metaphysical purity is necessary for any property to be a universal. This gives us the following criterion for settling the Main Question.

Criterion: If a property P is not metaphysically pure, then it is not a universal property.[7]

So why is it, according to Maudlin, that the properties on Lewis's list do not meet this criterion of metaphysical purity? His argument takes the form of a reductio: he first argues that there are no metaphysically pure intrinsic *relations*; consequently, there are no metaphysically pure intrinsic *properties*, for, if there were any, they would be sufficient to determine the would-be intrinsic relations.

The argument draws upon the fiber bundle formalism used in gauge theories such as quantum electrodynamics (QED) and quantum chromodynamics (QCD). Maudlin only sketches the intuitive ideas of the fiber bundle formalism without presenting the technical details. I'll rehearse his intuitive example here. You are asked to imagine two different arrows situated at two different points in space. The arrows would each seem to have the property of *pointing in a certain direction*. (The claim will be that properties in physics are, in a sense, just like directions.) And given those properties, the two arrows should stand in one of two relations: either they point in the same direction (they are parallel) or they point in different directions (they are not parallel). The trouble is that neither of these relations (being parallel or not) is metaphysically pure. Without an affine connection on the space, there is no fact of the matter as to whether or not the two arrows are parallel.

Why is it that we need an affine connection? To see this, Maudlin asks his reader to imagine that the two arrows are sitting at different points on the surface of a sphere. Now imagine moving one of the arrows over to the other so that you can check to see if they are parallel. The answer turns out to be different depending upon which path you took. So we have to relativize the property of *being parallel*: relative to one path the arrows are parallel,

[7] Thus metaphysical purity is a necessary, but perhaps not sufficient, condition for a property to be a universal property. Maudlin does not provide sufficient conditions for metaphysical purity, presumably because he only needs to show that this necessary condition cannot be met in order to conclude that there are no universal properties.

but relative to another path they are not.

The significance of this example is that the affine connection on the surface of a sphere is not flat, whereas the affine connection on Euclidean space is flat. Note carefully, however, that Maudlin's position is *not* that spaces with flat connections can give rise to metaphysically pure relations of *being parallel*, while only those spaces with curvature pose a threat to metaphysical purity. As he puts it,

> In a perfectly flat Euclidean space, the result is the same no matter which path is taken, but even in this case the *metaphysics* of parallelism is not that of a metaphysically pure relation: two distant arrows are only parallel in virtue of the affine connection along paths which connect their locations, even if the result of the parallel transport will be the same along any path. (p. 92) [Emphasis in the original]

So Maudlin's concern is not just that the result of comparing two arrows might be dependent upon the path taken to bring the two arrows together. Even in cases where the result is the same no matter which path is taken, he thinks there is a remaining worry, namely, that the comparison still cannot be made without the presence of an affine connection. So here the notion of metaphysical purity is operative: in a world with just the two arrows–and so *without* an affine connection–it is not possible to instantiate the relation of *being parallel*. So *being parallel* is not a metaphysically pure relation.

This point about the necessity of a connection for comparing directions is supposed to bear upon the question of universal properties, because, Maudlin says, "[g]auge theories apply exactly the sort of structures that we have used to explicate comparison of directions to other sorts of fundamental physical 'properties' or 'magnitudes' " (p. 94). The idea is that attributing a fundamental property to a fundamental particle is 'just like' attributing a specific direction to an arrow: comparisons of fundamental properties cannot be done without the presence of an affine connection any more than comparisons of directions can be done without the presence of an affine connection. And the necessity of the connection for comparing properties makes the sharing of any fundamental property metaphysically *impure*. Since the relation *having the same property* cannot be instantiated in a world without a connection, that relation cannot meet the necessary condition for metaphysical purity.

To make his argument, Maudlin takes up the case of quark colors as a concrete and illustrative example, intending for this argument to generalize to such cases as mass, electric charge, flavor, and any other would-be universal properties.

> Take, for example, chromodynamics, the theory of the force that binds quarks together. The easiest way to begin to describe the theory employs the language of universals: there are three color 'charges' ('red', 'blue', and 'green'), which are analogous to, e.g. positive and negative electric charge. There is a force produced between colored particles, like the electric force. This force is mediated by the gluons. And so on.
>
> If one were to take this language at face value, one would likely conclude that the three colors are metaphysically pure properties.... But chromodynamics is a gauge theory, which means that at base color charge is treated completely analogously to directions. (p. 94)

Since attributing a color to a given quark is (purportedly) just like attributing a specific direction to an arrow, comparisons of color require a connection:

> [E]ach point in the base space has a space of possible color states associated with it, but we have no means of comparing the states at *different* points with each other. In order to do this, we need to add something more, something which, intuitively, ties together the fiber at every point with the fibers of points that are infinitesimally close. This something more we need is a *connection* on the fiber bundle. Once we have a connection, we can do exactly (and only!) the sort of comparison we did with directions: given points p and q in the base space *and a continuous path connecting them*, we can 'parallel transport' a vector from the fiber over p along the path to the fiber over q. And just as for directions, the results of the comparison will in general depend upon the particular path chosen: there is no path independent fact about whether vectors in different fibers are 'the same' or 'different'. (p. 95-6) [Emphasis in the original]

Here we need to be extremely careful in evaluating Maudlin's argument. At first, his objection would seem to be that quark colors are path-relative, and that this relativity to the path is the reason that they cannot be universal properties. But upon closer inspection, it seems that, in Maudlin's view, the root of the issue is rather that the presence of a connection is necessary for making any comparison between two quarks, and that this precludes the comparison from being *metaphysically pure*. As he says, we need 'something more' in order to compare the states. Now, one might have thought that the necessity of the connection, the 'something more,' arises from the threat of path-relativity. However, tucked away in footnote 8, Maudlin clarifies that, just as in his example with arrows on a sphere, the threat of path-relativity is not his chief concern:

> If the connection were (in the appropriate sense) flat, the result of transporting a vector might be the same no matter which path is chosen. But this sort of path *invariance* should not fool us into thinking that the comparison is metaphysically path *independent*: comparisons can only be made if there are paths connecting the points. [Emphasis in the original]

So even if the results of a comparison are the same for any path, Maudlin still thinks that the path plays a metaphysically significant role. Imagine a world with just two quarks in it.[8] Is there any fact of the matter as to whether or not they have the same color, or the same electric charge? On Maudlin's account there is not, because such a world *lacks* a connection.[9] We must first add a connection to that world, and only then can we parallel transport one quark along the chosen path to reach the second quark, and then compare the two. Maudlin concludes,

> If we adopt the metaphysics of the fiber bundle to represent chromodynamics, then we must reject the notion that quark color is a universal, or that there are

[8]This world is not actually physically possible (given QCD), since quarks always come in bound states of three quarks, or in a bound state with an anti-quark. But for the sake of argument, we may pretend that it is.

[9]There's another potential ambiguity here: is the worry over metaphysical purity that the *path* is metaphysically something more, or that the *connection* is metaphysically something more? Maudlin seems to think that it is the *path*. But surely positing a world to begin with means to posit a spacetime, and surely spacetimes come with paths. So why should we think that the existence of a continuous *path* between the two points counts as an extra *thing* existing in the world? Perhaps what is really going on is this: since the base space of the fiber bundle is spacetime, that gives us a continuous path through spacetime connecting the two points in the base space, above which 'arrows' hang up in the total space. But the comparison we really want to make is between those two arrows. And without a connection, we have no way of bringing the arrow at one point in the total space over to the other arrow at another point in the total space, even though there are continuous paths down in the base space. That is, without a connection, we cannot utilize the extant paths for the purpose of transporting one vector over to the other.

> color tropes which can be duplicates, or that quarks are parts of 'natural sets' which include all and only the quarks of the same color, for there is no fact about whether any two quarks are the same color or different. Further, we must reject the notion that there is any metaphysically pure relation of comparison between quarks at different points, since the only comparisons available are necessarily dependent on the existence of a continuous path in space-time connecting the points. So it seems that there are no color properties and no metaphysically pure internal relations between quarks. And if one believes that fundamental physics is the place to look for the truth about universals (or tropes or natural sets), then one may find that physics is telling us there are no such things. (p. 96)

Maudlin clearly intends for this argument to generalize from the case of color charge to other properties such as electric charge and mass:

> Since metaphysicians like Armstrong have focused on examples like electric charge and mass in explicating the theory of universals, eliminating them requires a wholesale revision of that picture of universals (p. 102).

In summary, Maudlin's argument is this:

1. All universal properties must be metaphysically pure.
2. Fundamental property attribution is always just like attributing a specific direction to a vector.
3. Directions are not metaphysically pure.
4. Therefore, there are no universal properties.

There are a number of things one might say in response to this argument. For one thing, we might want a story about why the spacetime points at which the arrows are located do not count as extra things that exist over and above the arrows, yet the paths between the points and the connection both seem to count as extra things that exist.[10] How do we pick

[10]There is a case to be made for the metaphysical significance of the connection, since it is so closely related to the gauge field, but it is much harder to see why a path within the manifold should count as a extra thing that exists in the word. To be sure, the *math* requires that such paths exist within the fiber bundle we are using, but it is not clear that this means that the path through the manifold corresponds to some metaphysically weighty thing existing in the world represented by the fiber bundle. That is, we could think of the path as just part of the manifold structure we get from positing a possible world, in which case the path need not count as "something more." It is especially puzzling that Maudlin is willing to ascribe this level of metaphysical weight to the paths, given his expressed concern in this paper to warn against

out which parts of the mathematical formalism are ontologically relevant?[11]

But suppose that, for the sake of argument, we accept Maudlin's rules of the game: in order to test some property for metaphysical purity, we first posit a world (fiber bundle) inhabited with just two things (each represented by a vector). We then compare the two vectors to see whether or not the two things both instantiate the property in question. If we can settle this question *without* positing any additional things (such as connections on the bundle, or paths in spacetime) in the world, then the property passes the test, and that property is still a candidate to be a universal. But if, instead, we find that we cannot settle this question regarding the sameness of the property without additional things in the world, then the property fails the test, and it cannot be a universal property.

We have seen that, by using precisely this test for metaphysical purity, Maudlin argues that color charge cannot be a universal property. We have also seen that he takes his argument to generalize beyond the case of color charge to both electric charge and mass. I claim that this generalization fails. While there is *one* clear sense in which color charge is just like a direction, this does not carry over to either case of electric charge or of mass. Indeed, electric charge passes the metaphysical purity test, and so remains as a candidate for being a universal property. On the other hand, there is a strong sense in which mass does not pass the metaphysical purity test, but it fails the test in an entirely different way than the way in which (one sense of) color charge fails. Color charge, it turns out, is not perfectly representative of all the other fundamental properties that we encounter in particle physics.

While I will conclude that electric charge and two senses of color charge are metaphysically pure properties, I will not go so far as to claim that these properties are in fact universal properties. Maudlin has not given sufficient conditions for metaphysical purity, and I will not speculate as to what those may be. Thus, while I think we can be confident that

"illegitimately projecting the structure of our language onto the world," or of "mistak[ing] grammatical form for ontological structure"(p. 79). By that same token, if fiber bundles are the mathematical language for the physics, then the fact that the formalism of that language requires the existence of a certain mathematical object–and so in this context, a *linguistic* object–does not necessarily indicate that the theory requires the existence of a corresponding *physical* object in the world.

[11] See [Hirsch, 2017] for a response to Maudlin focusing on this question.

several different properties are candidates for being universal properties, the Main Question of whether or not there are in fact any universal properties remains open.

3 Three Notions of Color Charge

In order to substantiate these claims, it will be useful to first consider the case of color charge in more detail. In this case, I find three distinct levels of description for color charge and clarify how Maudlin's argument only applies to one of those levels of description. At the other two levels description, color charge passes the metaphysical purity test. In the next section I will argue that this analysis of color charge does not carry over to the cases of electric charge and mass.

There are, I claim, three distinct notions of color charge. In order to illustrate the distinction between these three notions, it will be instructive to consider color charge in analogy, not with electric charge as is usually done, but with the property of spin. Color charge and spin are both treated in particle physics using the representation theory of the Lie groups $SU(N)$: for color $N = 3$ and for spin $N = 2$. This relationship suggests that one can use interpretive principles that seem sensible for spin as a guide for finding analogous interpretive principles for color charge. This is not to say that we should think of color charge in exactly the same way that we think of spin; of course the analogy between the two will break down at some point. But the mathematical similarities make spin a good starting point for investigating the appropriate interpretation for color charge.

So, what do we mean when we ask, for a given particle, "What is the spin of this particle?" In fact, there are several possible meanings. First, we might mean to ask for what *kind* of spin it has, or *in what way* it is a particle with spin. In this case, the answer for all of the leptons (e.g. electrons, muons, quarks), is that these are spin-$\frac{1}{2}$ particles. Meanwhile the answer for photons is that they are spin-1 particles; similarly, Δ-baryons are spin-$\frac{3}{2}$ particles, Higgs bosons are spin-0 particles, and so on.

But at other times when we ask for a particle's spin, we mean to ask for a particular particle's spin state, e.g., 'Is *this* electron in the z-spin-up state or the z-spin-down state?' Once we specify the first notion of spin, namely, what *kind* of spin the particle has, or in *what way* it is a particle with spin, we can then determine the number of possible spin states that any particle of that kind of spin might occupy. For example, while the spin-$\frac{1}{2}$ particles can be in one of two z-spin states, the spin-$\frac{3}{2}$ particles can be in one of four different z-spin states. Mathematically, this number of different possible states is given by the dimension of the representation of $SU(2)$ used for particles with that kind of spin, and transforming according to a different representation of $SU(2)$ corresponds to having spin in a different way or of a different kind. Finally, at a still more general level, we distinguish between particles with spin at all and particles without spin. Thus, the spin-0 Higgs is said to be spin*less*, while all those that are not spin-0 are particles with spin.

This gives us three different levels at which we can specify the spin of a given particle: we determine first (1) whether the particle is spinless or otherwise has some non-zero spin; if the latter, then we determine second (2) in what *way* it has spin or what *kind* of spin it has (i.e., spin-1, spin-$\frac{1}{2}$, etc.); and third we can ask (3) which of the possible spin states, for a given kind of spin, a particular particle happens to be in.[12]

I claim that we have precisely the same three levels of description for color charge. At level (1) we may distinguish between particles with color charge *at all* and particles with *no* color charge. Gluons, quarks, and anti-quarks all have color charge, while the rest of the subatomic world carries no color charge at all. But at level (2) the gluons, quarks, and anti-quarks all carry color charge in different ways, and this is shown mathematically by the

[12] Arguably, the distinction between (1) and (2) is rather thin. We might instead collapse the two into one level, and then say that spinless particles *do* have a value for spin–it is just that that value is zero. At the end of the day, I don't think much turns on whether we take spinless and colorless to be ways of having spin and color, respectively, or if we maintain spinless and colorless as separate categories from having spin at all and having color charge at all. However, I have chosen the more pedantic route of maintaining this distinction between (1) and (2) because it is useful for understanding the metaphysical differences between electric charge and color charge: it is metaphysically noteworthy that gluons carry color charge while photons do not carry electric charge. Moreover, it is at level (1) where quarks and gluons are said to both carry color charge; at level (2) they have color charge in different ways.

fact that they each transform according to different representations of $SU(3)$. The (distinct) representations used for the quarks and the anti-quarks are both three-dimensional. So at level (3) there are three different possible color states for the quarks and three different possible color states for the anti-quarks. It is at this level of description that we say quarks come in three colors (red, blue and green) and that the anti-quarks come in the three anti-colors (anti-red, anti-blue, anti-green). Meanwhile, the representation for the gluons is eight-dimensional, and there are in this sense eight different ways for a gluon to have color charge, corresponding to various combinations of color and anti-color.

Recall that, for any group, a representation is a group homomorphism from the group G to the general linear group, $\mathsf{GL}(V)$, of some vector space V.[13] The dimension of the representation is the same as the dimension of V, and we refer to V itself as the 'carrier space' for the representation. The spin or color state (that is, the property of spin or color at the third level of description) of the particle is given by a vector in the carrier space.

For a spin-$\frac{1}{2}$ particle, we use the "fundamental" representation of $SU(2)$, which is two-dimensional. A set of basis vectors for the carrier space is used for the z-spin-up and z-spin-down states, and we usually choose to write them as:

$$|\uparrow\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |\downarrow\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}. \tag{1}$$

In precisely the same way, the three quark color states correspond to basis vectors of the carrier space for the first fundamental representation of $SU(3)$, whose carrier space is $\mathbb{C}^3$. We can write such a set of basis vectors as:

$$q_r = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}, \quad q_b = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \quad q_g = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}. \tag{2}$$

[13] See [Hall, 2000] for an introduction to group representations.

Then the color states of the anti-quark are given by basis vectors for the carrier space for the second fundamental representation of $SU(3)$, which happens to be dual to the quark color space:

$$\bar{q}_r = \Big(1, 0, 0\Big), \quad \bar{q}_b = \Big(0, 1, 0\Big), \quad \bar{q}_g = \Big(0, 0, 1\Big). \tag{3}$$

Thus, for both spin and color charge, the third level of description for specific spin or color states is given by a set of linearly independent directions in the carrier space of the relevant group representation. So at *this* level of description, Maudlin is correct: these state properties are treated *exactly* like directions. But not so for the first and second levels of description. At the second level sameness or difference of color charge (or of spin) is determined by whether or not the two particles transform according to the same representation of the relevant group. And at the first level, having color charge (or spin) at all is determined by whether or not the representations according to which the two particles transform are trivial. And these facts about group representations do not depend in any way upon any particular vector, or direction, in the carrier space.

Moreover, these levels of description are hardwired into the fiber bundle formalism of gauge theories. A gauge theory is formulated using a principal bundle, which comes equipped with the structure of a Lie group. Given a principal bundle, one can construct its various associated vector bundles, which come endowed with a representation of the principal bundle's Lie group. Matter fields are given by sections of these associated bundles. For example, the matter field for a quark is described in an associated bundle built using the first fundamental representation of $SU(3)$. So the moment we posit a world with a quark in it, we immediately have at our disposal the structure of this representation.

In light of these distinctions, consider again Maudlin's example of a world (fiber bundle) *without* a connection, and with just two quarks (whose color states are represented by two vectors) at different points.[14] Let's call these points p and q. The quark located at p has a

[14]It must be acknowledged that there are deep conceptual issues regarding how we can get something

color state represented by some vector in the Hilbert space H_p of color states at that point, and the quark across the way at q similarly has a color state represented by some vector in a Hilbert space H_q of color states. If we want to know whether or not these two quarks have the same color charge *at the most specific level of description* (Are they both green? Are they both blue? Are they both red?), then Maudlin is right in that we cannot answer this question without a connection. But if, on the other hand, we want to know whether or not they have the same color charge at either of the other two levels of description, then we can answer these questions in the absence of a connection. Since both H_p and H_q are carrier spaces for non-trivial representations of the structure group for QCD, all of the vectors in H_p and all of the vectors in H_q describe states of particles with color charge at the first level of description, that is, they describe particles with the property *being charged at all*. Similarly for the second level of description: the two quarks both have color charge *in the same way* because, by definition, both H_p and H_q are carrier spaces for the first fundamental representation. So at these two levels of description for color charge we do not need to check to see if the vector representing the states of the individual quarks are the same. What is relevant instead are properties of the entire vector space, not individual vectors. Consequently, we do not need the extra structure of a connection, or of a continuous path in space time connecting p and q, or any other such 'something more' over and above the two vectors representing the color states of the two quarks. This shows that the properties *having color charge at all* and *having color charge in a certain way* meet the necessary condition for being metaphysically pure. So it is possible that these properties can be thought of as universal properties.

It may be objected that the general property *having color charge at all* is contrived. The objection might go as follows. Suppose that we identify the property *being colored* with the disjunctive property *being red, blue, or green*. If that's the right way to think of *being colored*, then it looks like the specific color states are the operative properties for the physics,

like a particle interpretation out of these gauge theories to begin with. For the sake of argument, I'll follow Maudlin in glossing over the details, and assume that we can, at a minimum, think of property instantiations as state vectors of some Hilbert space at a point in space-time.

in which case *being colored* is not a good candidate for a universal property.

However, *being colored* does not amount to the disjunction of the three specific color-states, any more than *having spin* is the disjunction of *being spin up or being spin down.* For one, that would be to limit attention to the case of spin-$\frac{1}{2}$, and we certainly need to have a wider view of spin in general; it also neglects the fact that one can have states that are superpositions of these possibilities. Finally, *having color charge at all* is operative in the physics of QCD. We should think of *being colored* as a property that applies to all particles with states in the carrier space for *any* non-trivial representation of the color group $SU(3)$, not just to quarks. It is in this sense that quarks and gluons are both said to carry color charge. The fact that gluons carry color charge is vital to the physics of QCD. That gluons carry color charge, whereas photons do not carry electric charge, accounts for many of the important differences between QCD and the Abelian gauge theory QED. Thus, *having charge at all* should not be dismissed as contrived.

With that in mind, let's now run Maudlin's thought experiment for comparing color charges between one quark and one gluon, instead of between two quarks. Imagine a world with just one quark and one gluon. Let's say the quark is at point p and that the gluon is at point q.[15] As before, the quark's state is a vector in (a copy of) the three-dimensional carrier space of a fundamental representation of $SU(3)$ situated at p. The gluon, in contrast, has a state in the eight-dimensional carrier space of the adjoint representation of $SU(3)$.[16]

Suppose now that we wanted to ask the same question of the one quark and the one gluon that we previously asked considering the two quarks: are the quark and the gluon in the same color state? If we try to answer this question using Maudlin's test of seeing if the two vectors are the same, we cannot make sense of the result. The quark state is represented by one of the vectors in the three-dimensional space at p, whereas the gluon is

[15] It should be remembered that, for the sake of argument, we are ignoring a number of important details regarding how to understand something like a 'particle' as represented in a gauge theory. Recall note 14.

[16] In this case, there will also be a connection in the background, but it does not count as 'something more.' Since we have posited the existence of a gluon, the QCD gauge field, represented by the connection, must be present in the world as well. Since we cannot posit a gluon in a world without having a connection on the fiber bundle, the connection does not count as 'something more.'

represented by one of the vectors in the eight-dimensional space at q. No matter how we might try to transport one vector over to the other, there is no isomorphism between their respective vector spaces. So there is no sense in which the two vectors could possibly be the same vectors.[17]

Nevertheless, we can make sense of this question: are the quark and the gluon both *colored particles*, i.e., do they both have color charge in the most general sense? Here the test for answering this question is to look at what kind of vector space the particles' states live in. Here they both live in carrier spaces for non-trivial representations of $SU(3)$. Consequently, both spaces are such that all of their vectors can represent particles with the property *being colored*. We can also make sense of this question: do the quark and the gluon both have the same *kind* of color charge? Here the answer is No, because the fundamental representation is inequivalent to the adjoint representation. The ways in which they have color charge is different.

So it simply is not true that all properties in a gauge theory are treated exactly like directions. It is only at the third level of description that we find a directional property. Granting that the specific color states are not metaphysically pure, and so these properties cannot be universals, this is certainly not enough to show that physics is telling us that there are *no* universal properties.

Moreover, the metaphysical impurity of color charge at the third level does not follow just from the fact that we use fiber bundles to formulate gauge theories. Rather, I think that Maudlin's argument shows that, in general, fiber bundles are well-equipped to describe metaphysically impure properties using the group representations hardwired into the associated bundles. For an associated bundle using a multi-dimensional representation, the basis vectors of the carrier space for that representation are ready to describe some metaphysically

[17]There is, however, a closely related sense in which a given quark and a given gluon may or may not be in compatible charge states in order to interact with each other. To interact with a quark in a given color state, a gluon must carry the corresponding anti-color. Whether or not a gluon and a quark have compatible charge states is determined at the third level of description, which we have already said is metaphysically impure.

impure property. However, those same group representations can also be used to describe properties like color charge at the first and second levels. Fiber bundles allow for both the metaphysically pure and the metaphysically impure.

4 Why Maudlin's Argument Does not Generalize

In the previous section, I argued that color charge should be understood at three different levels of description, and that Maudlin's argument only succeeds with respect to one of those levels. In this section, I turn to addressing whether or not Maudlin's argument can generalize to the properties of electric charge and mass as he claims. In each case, we find that the 'directional' quality of color charge at the third level of description does not carry over to these other properties.

4.1 Electric Charge is not like Color Charge

Having seen three levels of description for color charge, one might expect that electric charge would have analogous levels of description. After all, these properties are supposed to be just two different kinds of 'charge' corresponding to two different gauge theories. In principle, much of what we have said about color charge does carry over to the case of electric charge, where the relevant group is $U(1)$: we can again distinguish between the trivial and non-trivial representations, and distinguish the non-trivial representations from each other, etc. However, in this case, the mathematical theory used to characterize the various representation is highly simplified. The groups $SU(3)$ and $SU(2)$ discussed above are both simple Lie groups, whereas $U(1)$ is not simple. Consequently, the $U(1)$ representations are characterized in a very different way. This can be used to show a few important ways in which electric charge is not like color charge.

The group $U(1)$ is the circle group, the set of numbers in the complex plane with unit modulus, $e^{i\theta}$ for $\theta \in [0, 2\pi]$. Its complex irreducible representations are all of the form

$$\rho_n(e^{i\theta}) = e^{in\theta} \tag{4}$$

where n is an integer. Moreover, each of these representations ρ_n are one-dimensional because this group is Abelian. Every carrier space for a complex, non-trivial, irreducible representation of $U(1)$ is isomorphic to $\mathbb{C}$.

At the first level we distinguish between those particles with electric charge at all, and those with no electric charge at all using the distinction between trivial and non-trivial representations. The trivial representation of $U(1)$ is ρ_0 since it maps each element of $U(1)$ to the identity. Any other ρ_n is a non-trivial representation. At the second level we distinguish between the various non-trivial representations themselves, which for $U(1)$ is accounted for by different non-zero integers labeling the representations.

Let's run the metaphysical purity test for electrically charged particles at these two levels. Imagine a world (fiber bundle) with just two electrons in it, one at point p and one at a different point, q. Electron states transform according to the ρ_{-1} representation of $U(1)$. Thus, there is one copy of $\mathbb{C}$ at p and another copy at q, and the states of the electrons are given by vectors within these carrier spaces for ρ_{-1}. Do the two electrons share the property *having electric charge at all*? Yes they do, because they each transform according to a non-trivial representation of $U(1)$. Do the two electrons have electric charge *in the same way*? Yes they do, because they each transform according to the same representation of $U(1)$. Now consider a world with one electron and one proton. Proton states transform according to the ρ_1 representation. Thus, the electron and the proton share the notion of electric charge at the first level of description, but not at the second. What if we were to compare an electron and a neutron? Neutron states transform according to ρ_0, the trivial representation of $U(1)$, since this particle is electrically neutral. Thus, the electron and the neutron do not share the property of electric charge at either the first or the second level.

As before in the case of color charge, one can thusly run the metaphysical purity test for electric charge at these two levels *without* determining whether or not the fiber bundle is equipped with a connection or with continuous paths, or anything else beyond the mathematical structure used to represent the two particles. Once we posit the existence of the particles, we immediately have the structure of the relevant group representations at our disposal. And this structure is sufficient for determining sameness or difference of electric charge at the first and second levels of description. Therefore, electric charge at these two levels passes the metaphysical purity test.

The reader will doubtless have noticed that the integers labeling the representations for the electron, proton, and neutron equal the *amount* of electric charge that is said to inhere in these particles. This is no coincidence. When $U(1)$ representations are used for electric charge these integers n correspond to the eigenvalues of the charge operator.[18] That is, these integers n are used to encode physical information about the *net amount* of electric charge present in a state that transforms according to ρ_n.

What about the third level of description? For electric charge, things are quite different at this level. For color charge and spin, the third level describes specific property states picked out by different basis vectors in the carrier space of the representations. Thus the two spin states (up and down) arise in the two-dimensional representation of $SU(2)$, and the three quark color states arise in a three-dimensional representation of $SU(3)$. But for $U(1)$ the carrier space is a *one*-dimensional complex vector space. Understood as such, this space simply does not have multiple directions in which its vectors could point, and consequently, vectors in this space *could not possibly* point in different directions. Since the carrier spaces are all $\mathbb{C}$, individual unit vectors in these spaces can differ *at most* by a phase. While the full extent of the physical significance of a phase factor is a matter of some debate, differences of phase have never been taken to correspond to differences of electric charge in any sense. Thus, it seems that the third level of description simply does not apply in the case of electric

[18] See [Woit, 2015] chapter 2.

charge. Electrically charged particles cannot be in various different 'electric states' in the way that color-carrying particles can be in various different color charge states.

This leaves the first and second levels as the only relevant levels of description for electric charge. Yet, for electric charge, we may collapse the conceptual distinction between these two levels into just one notion of charge, the notion of *net amount* which is encoded in the integer labels for the representations. *Having electric charge at all* is the same thing as *having a non-zero net amount*, and *having no charge at all* is the same thing as *having net amount zero*. *Having electric charge in different ways* is the same thing as *having different amounts of electric charge*.

So we have a surprising disanalogy between color charge and electric charge. The metaphysics of electric charge is much thinner than that of color charge. In order to understand how it is said that certain particles have color charge, we need all three levels of description. While there is no mathematical difficulty with defining the three levels for electric charge, doing so is not very illuminating. Electric charge is thus not like color charge.

4.2 Mass Is Not Like Color Charge

Maudlin takes his argument against universal properties to generalize beyond color charge and electric charge to include mass as well. I have argued that the mathematical structure used to describe electric charge reveals an important disanalogy between color charge and electric charge, such that Maudlin's argument does not carry over from color charge to electric charge. The sense in which mass is not like color charge is even stronger in that group representations do not have the same role to play for mass as they do for both color and electric charge. Mass appears within the fiber bundle formalism in a different way than charge does.

In the initial formulation of any gauge theory, the fermion particles described by the theory have some quantity of mass, either positive or zero. The mass is identified in the Lagrangian of the theory as a constant parameter in a term of the form $m\psi\bar{\psi}$. The field ψ

is a section of an associated bundle, and it is the sort of mathematical object that transforms according to the appropriate group representation. But the parameter m, which is interpreted as mass, is not at all affected by the group transformations. Mathematically, it is just some real number multiplying another real number, $\psi\bar{\psi}$. And, much unlike the vectors of $\mathbb{C}^3$ used to describe color states, there is nothing inherently directional about a real number. This is why Maudlin's argument for the metaphysical impurity of color charge does not generalize to the case of mass. His argument rests on the claim that using fiber bundles as the mathematical setting for gauge theories implies that all properties are directional in the way that color charge at the third level is directional. But mass is a property in gauge theories that is not directional.

This is not to say, however, that mass is therefore a metaphysically pure property. There are good reasons to think that the ultimate notion of mass we find in particle physics is not at all metaphysically pure, but for entirely different reasons than those given for color charge. In the Standard Model of particle physics, the Higgs boson is necessary in order to account for the mass of all those particles that have any mass at all. Moreover, renormalization and regularization of the gauge theories in the Standard Model lead to a notion of mass that is often explained in terms of interactions with a cloud of virtual particles. Any property that depends upon the existence both of the Higgs and of a number of additional virtual particles is certainly not metaphysically pure.

The Higgs accounts for the masses of other particles in two different ways, one for the fundamental fermions (such as quarks and electrons) and one for the intermediate vector bosons (the $W^{\pm}$ and the Z). The way in which the Higgs gives mass to the intermediate vector bosons is through the famous Higgs mechanism. Spontaneous symmetry breaking leads to massless Goldstone bosons, and the massive $W^{\pm}$ and Z are said to result from the Higgs 'eating' the Goldstone bosons. The expressions for their masses are given as follows:

$$m_{W^{\pm}} = \frac{gv}{2}, \qquad m_Z = \frac{m_{W^{\pm}}}{\cos\theta_W} \tag{5}$$

where g is the weak coupling constant, v is the Higgs vacuum expectation value, and θ_W is the weak-mixing angle. This θ_W is the angle of rotation in a two-dimensional vector boson plane that gives rise to the photon and the Z bosons as orthogonal directions in an $SU(2)$ representation. So there clearly is *some* sense in which directional properties are important to this theory. In particular, we might take the photon and the Z bosons to be represented precisely by directions in the carrier space for a two-dimensional $SU(2)$ representation. However, while this is in the background behind how we derive quantities of mass, the properties of *mass* that we attribute to the $W^{\pm}$ and the Z are not these directional quantities, but instead real numbers determined straightforwardly by equation 5. So again, mass in this context is not a directional property in need of a connection in order to be meaningfully compared. Rather, the mass of the $W^{\pm}$ and the Z is dependent upon the existence of the Higgs and its ability to transform Goldstone bosons. Since the intermediate vector bosons can only have their masses in a world with a Higgs, their masses are likely not metaphysically pure.

The fermions, in contrast, gain their mass through a Yukawa interaction with the Higgs. While directly writing down fermion mass terms as above is the simplest way to get mass in a general gauge theory, this approach runs into problems in the context of the full Standard Model. The Standard Model must include an account of parity violation, the phenomenon that the weak interaction discriminates on the basis of handedness: left-handed particles and right-handed antiparticles participate in the weak interaction, while right-handed particles and the left-handed antiparticles do not. The way that we account for parity violation spoils the simple approach to getting mass terms, since those terms are no longer invariant under the symmetry of the electro-weak gauge theory. The interaction with the Higgs is necessary for restoring invariance. Using the interaction with the Higgs, the fermion masses are given by expressions of the form

$$m = \frac{gv}{\sqrt{2}}, \tag{6}$$

where g is the Yukawa coupling of the particle to the Higgs field, and v is again the vacuum expectation value of the Higgs, and the result is a real number value for mass. Thus, in this context of fermion masses, the mass property is not directional in the sense that color charge states are directional, but it could still be thought of as metaphysically impure, since fermion masses depend upon the existence of the Higgs.[19] In a world with just an electron and no Higgs, the electron would have no mass.

5 Concluding Metaphysical Morals

Let's return now to the Main Question: are properties like mass, electric charge, and color charge universal properties? I have argued that color charge at the third level of description fails the metaphysical purity test, while the other notions of color charge pass the test. Electric charge does not display the same three-fold conceptual complexity of color charge, and has instead just level of description in terms of the net amount of electric charge. And this notion of charge is metaphysically pure. Mass also is unlike color charge, lacking any directional quality. But all of the particles in the Standard Model depend upon the Higgs for their masses in a metaphysically impure way. So the use of fiber bundles in gauge theories allows for both the metaphysically pure and the metaphysically impure. Since the metaphysical purity test only serves to check for a necessary condition of universal properties, it is still an open question as to whether or not we should think of these properties as *in fact* being universal properties. It might turn out that they fail to meet some as yet unspecified sufficient condition. But until such sufficient conditions are produced, I think that electric charge and two notions of color charge remain as candidates for being universal properties.

My argument is largely based on an unexpected analogy between color charge and spin—and a disanalogy between color charge and electric charge. One might wonder why this analogy between spin and color charge is easy to miss. I will sketch a possible explana-

[19] There is a further complication in that quark states 'mix': the actual quark fields that interact with the Higgs can include, for instance, combinations of both up and down quarks. This sort of mixing seems to constitute an additional threat to the metaphysical purity of the individual types of quarks.

tion for why this is, and consequently why it is easy to miss the three-fold notions of color charge that I have identified here. In physics and philosophy discussions alike, one usually introduces color charge in the first place as an analogue of electric charge. Pedagogically, introducing color charge in this way is a natural place to start. In a physics class especially, it makes good sense to begin with the simpler theory, QED, and then introduce the more complicated theory of QCD in reference to what is already understood from the study of QED. Moreover, the theorists who first constructed QCD did so with a conscious effort to generalize the methods of QED. So we should not think that there is anything inherently misleading about introducing color charge as an analogue of electric charge. However, the analogy is fundamentally about the functional role played by the charges *within their respective theories*. As electric charge is *in QED*, so color charge is *in QCD*. This does not imply that the metaphysics of electric charge and color change must be the same. Indeed, since QCD and QED are in certain crucial respects very different theories, the nature of the property that plays the role of charge in each theory need not be exactly the same. And so electric and color charge need not be exactly similar properties.

I think that a failure to recognize this point is part of what goes wrong in Maudlin's assessment of color charge, and in Lewis's approach to writing down a list of properties from physics to be used in metaphysics in some univocal way. We are familiar with electric charge, and it is the sort of property that can be used to categorize particles. When we hear that color charge is an analogue of electric charge, we might mistakenly expect that it will be able to do this same metaphysical work of categorization, distinguishing one kind of particle from another in just the same way that electric charge does. Maudlin's argument that the quark colors cannot be universal properties is only a problem for the metaphysician who expected to be able to use color charge in all the ways she is able to use electric charge. But the analogy between the two properties never licensed color charge for that work in the first place.

Insofar as I have tried to demonstrate clear senses in which electric charge and color charge are *not* analogous, it is important to clarify in what other sense they *are* analogous. Maudlin suggests that the analogy goes as follows.

> The easiest way to begin to describe the theory [of QCD] employs the language of universals: there are three color 'charges' ('red', 'blue', and 'green'), which are analogous to, e.g. positive and negative electric charge. There is a force produced between colored particles, like the electric force. This force is mediated by the gluons. And so on. (p. 94)

The thought is that somehow 'red', 'blue', and 'green' are analogous to positive and electric charge. Perhaps we can read Maudlin as follows: where there is a two-place relation between positive and negative electric charge (as opposites), there is a corresponding three-place relation between red, blue, and green. However, inspecting again the group theory at work here shows that this will not work. We saw above that the colors correspond to the three basis vectors for the first fundamental representation of $SU(3)$. But for electric charge, the relevant group is $U(1)$, whose representations are all one-dimensional. And so positive and negative electric charge cannot be related as two different basis vectors for some two-dimensional carrier space. Indeed, they are linearly dependent.

Instead, the relationship between positive/negative electric charge and color charge is this: *positive electric charge is to negative electric charge as red is to anti-red, as blue is to anti-blue, and as green is to anti-green.* Just as an up quark, say, has for its antimatter counterpart an anti-up quark with matching anti-color, the electron has for its antimatter counterpart the positron. And positrons differ from electrons only in so far as they have positive electric charge while electrons have negative electric charge. The relationship between positive and negative electric charge is the general relationship of charge and anti-charge.[20]

The analogy between color charge and electric charge is best understood at the first level of description, and only at this level. This is the level of *being charged at all*, and not at the level of the more specific color states. Having the property *being color charged at all* makes

[20]Group theoretically, a matter state is related to its corresponding antimatter state by the charge conjugation operator. For more on conjugation as the key to understanding antimatter, see [Baker and Halvorson, 2010].

a particle eligible for participation in the strong interaction in just the same way that *being electrically charged at all* makes a particle eligible for participation in the electromagnetic interaction. At the other levels of description, electric charge and color charge are not analogous.

Finally, where does this leave the traditional metaphysician? Should she be worried that color charge at the third level is not metaphysically pure? I think that she has at least two avenues for rebuttal on this point. First, if the traditional metaphysician did want to retain metaphysical purity for all properties, including color charge at the third level, then I think that she has a move available. She could choose to think of quark color states as dispositional properties, the sort of property that grounds how the color state of a quark *would* change *if* there existed a connection in that world, and *if* the quark were to be parallel-ly transported with respect to that connection along some path. Arguably, there can be facts of the matter about whether or not two quarks have the same such dispositional properties describing how each would behave under the relevant conditions, even in worlds where those conditions do not obtain. So under this dispositional conception, quark color states too would pass the metaphysical purity test, and so could be thought of as universal properties.[21]

Alternatively, she could use the distinction between essential and accidental properties to her advantage. Having accepted Maudlin's test for metaphysical purity, she would then expect that the test is worth running for *accidental* properties, but that *essential* properties would pass the test automatically. Essential properties are such that entities have them by definition. Hence, the moment one posits a world inhabited by just two entities of a given kind (e.g. two quarks) those two entities must share whatever properties define their kind. The essential properties, in other worlds, delimit the joints of nature around which universal properties must be able to carve. Accidental properties, in contrast, are

[21] This dispositional conception could also help the traditional metaphysician deal with the metaphysical impurity of mass. In a world with just fermions and no Higgs, the fermions could still have the *capacity* to interact with a Higgs, should one appear. And that capacity could be metaphysically pure. Additionally, particles with mass depend upon the Higgs for that mass. This includes the Higgs itself. The Higgs is self-interacting, and so generates its own mass. Thus the Higgs mass itself is perhaps metaphysically pure, and could serve as a sufficient foundation for building up a larger metaphysical theory of mass.

not required to do this same metaphysical work. In Lewis's language, accidental properties may be "abundant" rather than "sparse." I think that, if Maudlin were able to show that physics implies that (even just a few of) the essential properties of fundamental particles are metaphysically impure, then he would have a strong case for calling for a substantial revision of the traditional metaphysical picture of universal properties. But he has only shown that one accidental property, namely color charge at level (3), is metaphysically impure. And if that is right, then the traditional metaphysician has simply learned that an interesting and important accidental property turns out to be metaphysically impure. But I see no reason to think that the traditional metaphysician needed it to be the case that all accidental properties are metaphysically pure.

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