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Doing Away with Dispositions: Powers (Modality?) in the Context of Modern Physics[1]

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Abstract

Recent accounts of dispositionalism have extended this stance from vases to quarks. Here I shall present an obstacle to such an extension in the form of the symmetry principles that play such a fundamental role in the Standard Model of elementary particle physics. After considering certain ways the dispositionalist might get around this obstacle I shall argue that in its standard 'Stimulus and Manifestation' form, this stance should be abandoned. However, this does not mean one should give up on modal metaphysics entirely and adopt some form of Humeanism. Instead I shall suggest that current metaphysics presents certain 'tools' that might be deployed in this context, such as Vetter's recently developed notion of 'potentiality'. Thus there is still hope for a form of naturalised metaphysics that draws on extant metaphysical devices.

Key words

dispositions; potentiality; spin; Standard Model; symmetry.

1. Introduction

The metaphysics of science has become something of a 'hot' topic in recent years with debates over the tri-partite relationship between metaphysics, science and the philosophy of science engendering a range of views. At one end of the spectrum we find a form of extreme naturalism that insists that metaphysics must cut its cloth entirely to fit the contours of the relevant science, typically fundamental physics. One can

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identify such a view in the opening chapter of Ladyman and Ross's *Everything Must Go* (2007), where they run through a variety of claims and positions in current metaphysics, picking them off one by one and dismissing them for failing to mesh with modern physics. A somewhat more moderate tone can be found in Callendar (2011), but again the message is clear: philosophers of science have little to learn from metaphysicians who have signally failed to keep up with developments in science.

This is not my stance. Together with Kerry McKenzie, I have tried to articulate what we have called the 'toolbox' approach to metaphysics, according to which metaphysics can be viewed as providing a set of tools that philosophers in other sub-disciplines, and particularly, the philosophy of science, can use for their own purposes (French and McKenzie 2012). This approach can be broadly divided into two phases: we begin by noting that modern metaphysics has, for whatever reasons, set off along a different path from much of the philosophy of science, which has taken it further and further away from what are generally understood to be the fundamental features of science, particularly physics. As a result, current discussions about gunk and simples, or even 'core' notions such as intrinsicality and fundamentality, seem to bear little relation to how scientists conceive of the world. However, we nevertheless think that metaphysics offers an array of moves and manoeuvres, devices and techniques, etc., that can be profitably deployed to elaborate an understanding of the world that does mesh with what science tells us, where we take that understanding to, minimally, go beyond a straightforward recitation of the scientific details.

I think this offers a useful way of tackling issues to do with the ontology of modern physics (French 2014). However, there is an obvious tension that arises, which can be summarised as follows: how can we distinguish between that metaphysics that can be profitably used as a 'tool' in understanding the world, and that which should be thrown away, given that we cannot foresee what new views of the world science, and in particular, fundamental physics, will come up with? The response is to note (McKenzie and French forthcoming), that the toolbox approach is conditionalised twice over: first, of course, upon naturalistically inclined metaphysicians taking tools from the toolbox, instead of making them 'to order' as it were, and thereby completely sidelining traditional, analytic, non-naturalised metaphysics; and secondly, upon those tools actually being useful to the interpretation of science as it develops.

Thus, the extent to which modern metaphysics can be viewed as relevant in the context of scientific developments is dependent upon features external to the enterprise itself – features that have to do with the evolution of both science and the philosophy of science. Nevertheless, whatever conditionalised support metaphysics gets from naturalistic projects, it remains the case that metaphysicians themselves should concede that the systematic disregard of real science that is so prevalent in current discussions simply cannot continue if they are to take their own projects seriously (ibid.).

With that in mind, here's how the toolbox approach works in the context of this volume: within phase one, both dispositional and Humean accounts of laws and associated properties can be dismissed on the grounds that they fail to mesh with or even acknowledge in some cases certain features of fundamental physics. Here I shall focus on dispositionalism, as standardly understood (for criticism of Humeanism in this vein, see McKenzie 2013). In phase two, certain recent developments in the discussion over powers and dispositions may be examined with a view to their providing useful tools in constructing an appropriate account of modality in the context of modern science.

Thus the plan of the essay is as follows: in section 2, I shall outline the standard dispositionalist account. I emphasise 'standard' because I recognise that, to put it flippantly, if you were to collect 10 defenders of dispositionalism or 'powers' views more generally and put them in a room, you would get 15 different accounts! Indeed, my aim is to draw on some features of certain non-standard perspectives later in the essay. I shall then note how this account has been extended from the everyday to the realm of modern physics – from vases to quarks, in effect. Here, however, there is a fundamental obstacle: the role of symmetries as constraints on the fundamental laws in physics, which I shall outline in section 3. One of the great virtues of the standard dispositionalist account is that it supposedly yields laws from dispositions but it remains unclear, at best, how it can accommodate such symmetry principles.

I shall indicate some ways the dispositonalist might try to do that in sections 4 and 5 but in effect I will close off each option by indicating how the problem merely gets pushed back a step or two. Ultimately, the dispositionalist will have to ascribe her dispositions to objects that are metaphysically very 'thin', in the sense that they are mere placeholders within the physical structure, and also give up the standard Stimulus and Manifestation account, as I shall argue in section 6 and 7. Of course, that will be music to the ears of certain other critics within and outwith the powers camp and I will conclude, in section 8, by considering some recent proposals and evaluating whether they might be 'fit for purpose' within the context of modern physics.

2. Dispositionalism: The Standard Account

Let me begin with what I take to be the 'classic' statement of dispositionalism: Dispositional properties are those that play, as a matter of conceptual necessity, a certain causal role that is best captured in conditional terms (see, e.g., Mumford 1998). The equally classic example is that of fragility, understood in terms of the disposition to crack or break under appropriate circumstances, with the former taken to be the manifestation of the disposition and the latter circumstances, whatever they may be, as the stimulus. Thus the standard account is often framed in terms of the *Stimulus and Manifestation Characterisation (S&M)*:

for a property to be dispositional is for it to relate a stimulus (S) and a manifestation (M) such that, if an object instantiates the dispositional property, it would yield the manifestation in response to the stimulus; or a little more formally: $\forall x((Px \,\&\, S\,x) \rightarrow Mx)$, where P is the relevant property, S the stimulus and M the manifestation, of course.

Here I shall set to one side all the much pored over issues about what counts as a stimulus, or a manifestation, the impact of finks, blockers and so on, simply because they are typically not relevant to the kinds of situations I shall be considering.

However I shall mention, at least, what is taken to be a significant positive feature of this account, which is that it yields the laws of nature and thereby grounds their modal robustness (see Bird 2007). In particular, if one accepts what is sometimes called the Dispositional Identity Thesis, in terms of which the identity of properties is entirely cashed out in dispositional terms, so that, in effect, this identity is given by their place in the modal structure, then, adopting the above formal expression of S&M, laws can be seen to 'flow from' the relevant set of dispositions. And if we then consider a different possible world, populated by the same set of objects, then we will have the same properties, and hence by the Dispositional Identity Thesis, the same dispositions and the same laws, thereby accounting for the (physical) necessity of laws.

Over the last fifteen years or so the account has been extended from everyday entities and their properties, such as vases and window panes, to the sorts of objects we find in physics, such as electrons and quarks. One of the most significant statements of such an extension, if not the earliest, can be found here:

> Physics tells us what result is apt to be produced by the having of gravitational pull or of electromagnetic charge. It does not tell us anything else about these properties. In the Standard Model the fundamental physical magnitudes are represented as ones whose

> whole nature is exhausted by their dispositionality: that is, only their dispositionality enters into their definition. Properties of elementary particles are not given to us in experience: they have no accessible qualitative aspect or feature. There is no 'impression corresponding to the idea' here. What these properties are is exhausted by what they have a potential for doing, both when they are doing it and when they are not. (Molnar 1999, p. 13)

There are of course many ways in which one can critique this statement. One can point out that it relies on a narrow understanding of 'experience' and argue that although quark confinement may prevent us from gaining epistemic access to single quarks, we can certainly 'experience' their properties, such as strangeness, beauty, charm etc., *via* quark jets and the like, where 'experience' is understood in non-empiricist terms. As for electrons and their property of charge, even forty-five years ago (when I was studying physics at school), school-children had access to them (again, on a non-empiricist understanding of 'access') and their properties via reproductions of Millikan's famous oil-drop experiment! And of course it is an argumentative leap from a supposed lack of epistemic access to the denial of quiddities, which presumably are not intended to be accessible in the first place. More importantly, it is simply not the case that the nature of the fundamental properties of modern physics is exhausted by their dispositionality, at least not as the latter is understood on the standard account (see French 2013, 2014). Indeed, this is precisely the point I shall be exploring here.

Nevertheless, the extension of a dispositionalist stance to physics and the attendant claim that the fundamental properties of nature are (essentially) dispositional is now commonplace among dispositionalists of various stripes. Thus, Chakravartty asks,

> Why and how do particulars interact? It is in virtue of the fact that they have certain properties that they behave in the ways they do. Properties such as masses, charges, accelerations, volumes and temperatures, all confer on the objects that have them certain abilities or capacities. These capacities are dispositions to behave in certain ways when in the presence or absence of other particulars and their properties. (Chakravartty 2007, p. 41)

In similar vein, Mumford asserts that,

> [p]hysics in particular seems to invoke powers, forces and propensities, such as the spin, charge, mass and radioactive decay of subatomic particles (Mumford 2011, p. 267).

Here, just to continue with the somewhat churlish tone, one might wonder on what basis radioactive decay is set alongside spin, charge and mass, where the latter are fundamental properties, sometimes, and problematically (see French and McKenzie

2012) regarded as 'intrinsic', whereas the former is a phenomenon that results from quantum tunnelling. Nevertheless, that spin in particular is taken to be ultimately dispositional is something I shall be interrogating in some detail later on.

Before I get stuck into the physics it is worth noting that this broad picture of dispositions yielding laws has been attacked from a number of different directions. Thus Vetter, for example (Vetter 2009), has argued that what we get via the S&M characterisation is not the relevant law, per se, but a series of conjunctions of the form $\forall x((Px \ \& \ S_1x) \rightarrow M_1x) \ \& \ \forall x((Px \ \& \ S_2x) \rightarrow M_2x)$ … So, consider the much used example from physics of bringing a test charge in from infinity to a charged particle. S_1 will be the stimulus of placing the test charge at position r_1, and M_1 will be the relevant manifestation of the charge disposition possessed by the particle, which will either be the force felt or the acceleration experienced, depending on one's analysis of dispositional manifestations. Likewise, S_2 will be the stimulus of placing the test charge at position r_2, and M_2 will be the relevant manifestation of the charge disposition possessed by the particle … rinse and repeat. However, Vetter insists, a set of conjuncts is not a law – in effect what we have in our example is a set of instances of Coulomb's Law, not the law itself – and the dispositionalist is then faced with an explanatory gap, namely that of accounting for why the conjuncts all have the same form.

Mumford, on the other hand, has argued that if laws 'flow from' or supervene on dispositions, then we can eliminate the former from our metaphysical pantheon (Mumford 2006). Granted, as he notes, there is a tension between the dispositionalist account and the governing feature of laws which non-Humeans tend to emphasise, many philosophers of science would take such eliminativism as effectively a *reductio* of the account itself (although one could moderate this position by insisting that such eliminativism does not imply that we cannot talk of laws in scientific practice, or in philosophical reflection upon that practice, but that such talk should be seen as short-hand for a list of the relevant dispositions – a shift that is curiously akin to the Humean analysis of this talk!)[2]. Furthermore, as I shall suggest here, it is, at the very least, not at all clear that dispositionalism can accommodate symmetries in a similar manner and hence the kind of eliminativism that Mumford envisages may founder on this obstacle.

[2] Although it almost goes without saying that the two analyses differ profoundly when it comes to causation!

Typically the laws that are claimed to 'flow from' dispositional properties are understood as causal laws and the causal role of dispositions is explicitly incorporated into the characterisation of this account, as I have indicated above. Immediately one might then doubt whether the account can be extended to the quantum realm, where attributions of causation are famously problematic.[3] More generally, Saatsi has focussed critically on the claim that a property's 'causal profile', understood as its potential for entering into causal relations with other properties, can be nicely captured on this account in dispositional terms (i.e., via its causal powers; Saatsi forthcoming). However, setting aside the issue that he also discusses of whether such causal relations have a home in the quantum domain, there is more to charge, to use that example again, than is captured by its causal role (as expressed – setting aside Mumford's and Vetter's concerns – via Coulomb's Law in classical physics). In particular, there is the fact that charge is conserved, something that falls outwith its causal role. It then transpires that such conservation of properties can be related to certain fundamental symmetries (via Noether's Theorem; see Brown and Brading 2003) and in the case of charge, the relevant symmetry has to do with the gauge invariance of the electromagnetic field. Indeed, as Saatsi points out, it can be argued that much of the dynamical behaviour associated with charge can be attributed to this symmetry in the quantum context (Saatsi forthcoming). Thus, there are aspects of this property, its behaviour, the way it features in the relevant laws etc., that the standard dispositional account cannot seem to capture.

Relatedly it has been argued that the role of such symmetries in modern physics lies beyond the scope of dispositionalism (French 2014; Cei and French 2014) and what I shall do in the rest of this essay is explore some possible responses to this argument, indicate how these responses run into the sand and then consider how one might draw on certain recent suggestions that go beyond the standard dispositional account in order to appropriately capture the modal features of modern physics.

3. Symmetries in Physics

There has been an enormous amount written about symmetries in physics, particularly in the popular science literature. Here's a representative statement from a well-known advocate of their role:

[3] I'd like to thank Juha Saatsi for pointing this out.

> Nature, like an enemy, seemed intent on concealing from us its master plan. … At the same time, we did have a valuable key to nature's secrets. The laws of nature evidently obeyed certain principles of symmetry, whose consequences we could work out and compare with observation, even without a detailed theory of particles and forces. There were symmetries that dictated that certain distinct processes all go at the same rate, and that also dictated the existence of families of distinct particles that all have the same mass. Once we observed such equalities of rates or of masses, we could infer the existence of a symmetry, and this we thought would give us a clearer idea of the further observations that should be made, and of the sort of underlying theories that might or might not be possible. It was like having a spy in the enemy's high command. (Weinberg 2011, p. 1)

Here we have symmetries playing what is essentially a heuristic role in uncovering not only further observations but new theories. This is well-documented in the philosophy of science (see, for example, Post 1971) and numerous examples can be given but let us consider gauge invariance again: this refers to the way in which the Lagrangian of a system – which basically captures the dynamics of that system – remains invariant under a group of transformations, where the 'gauge' denotes certain redundant degrees of freedom of that Lagrangian. Such a group of transformations is represented via the mathematics of group theory and the generator of the group then represents a field. When such a field is quantised, we get kinds of quanta called gauge bosons.

I'll explain what a boson is shortly but if we take electrodynamics, for example, the relevant gauge symmetry group associated with the property of charge is labelled U(1) and the gauge boson that effectively drops out of the requirement to achieve gauge invariance is the familiar photon. This requirement of gauge invariance can then be extended to the other forces in physics and to a significant extent the (in)famous Standard Model of elementary particle physics was constructed on the back of this extension with the weak nuclear force (associated with radioactive decay listed by Mumford above) accommodated via the so-called SU(2) symmetry group associated with isospin (a property of protons and neutrons), and with the strong nuclear force (responsible for binding the nucleus together) associated with the so-called SU(3) symmetry group which operates on the colour property of quarks. Thus the Standard Model is fundamentally a gauge theory, associated with the groups SU(3) x SU(2) x U(1) via which the relevant symmetries can be captured within the theory. With the Higgs boson associated with the breaking of the isospin symmetry of the unified electro-weak force and responsible for the acquisition of mass, we have a complete picture of the fundamental forces, with the exception of gravity of course (how this can be unified with the Standard Model remains an on-going area of intensive research, but certain theories of quantum gravity have been constructed on the basis of gauge invariance, with the graviton as the corresponding gauge boson).

Now, as I said, I shall return to this picture below, but the point I want to emphasise here is the fundamental importance of gauge invariance and, more generally, of symmetry as a heuristic principle in the construction of the Standard Model. Of course, that's all well and good from the perspective of the philosophy of science but what bearing does all this have on the *metaphysics*? If one is an empiricist, constructive or otherwise, one might be tempted to stop there and simply note this heuristic role or perhaps, going a little further, that symmetry is the 'key' to theory (van Fraassen 1989). But if one has realist inclinations, one might be inclined to argue that this role signifies more than this and that the ubiquitous nature of symmetries in modern physics reflects their status as fundamental features of the structure of the world (French 2014). However one conceives of that status, there is the issue of the relationship of such symmetry principles to the familiar laws of physics. Here one can follow Wigner, one of the earliest explorers of the role of symmetries in physics (together with the great mathematician Weyl), who articulated the view that symmetries should be regarded as meta-laws, in a sense, or *constraints* on the more familiar laws of nature (Wigner 2003).

To indicate what is meant here, consider the most fundamental equation of quantum theory, namely Schrödinger's Equation:

$$i\hbar\frac{\partial|\varphi(n_i)>}{\partial t} = H\,|\varphi(n_i)>$$

where H denotes a specific Hamiltonian (taken out of another toolbox!) and the n_i denote the state-independent properties that identify the kind of particle involved. It is worth noting that to describe this as a law is not to do it justice. In effect Schrödinger's equation is a kind of 'uber-law' that operates at a very high level of generality. We only get laws applicable to specific systems once we plug in the relevant Hamiltonian (Cartwright 1999 refers to this as 'fitting out' the equation to yield a concrete model of a physical system). Thus, Schrödinger's equation acts as a kind of structural constraint itself on the laws of specific systems.

To attribute a property to a particle obeying one of these specific laws, the operator for that property must commute with the corresponding Hamiltonian (in the sense, to put it a little crudely, that it doesn't matter whether one applies that operator first to the state function describing the system or the Hamiltonian). Sets of such operators may form a group which represents a symmetry of the system (see McKenzie forthcoming, for a clear presentation). By virtue of the requirement that these operators must commute with the relevant Hamiltonian, the symmetries can be viewed as acting as constraints on particular Hamiltonians and their associated particular laws. Hence the specific laws obtained from Schrödinger's equation are constrained in ways that do not sit comfortably with dispositionalist accounts (see Cei & French 2014). To flesh this out, let's consider a specific example: Permutation Symmetry, which plays an absolutely fundamental role in quantum physics.

Consider the possible arrangements that arise from distributing two particles between two boxes, representing states. In classical 'Maxwell-Boltzmann' statistics we obtain four possible arrangements: both particles in the left hand box, both in the right hand and one in each, the latter arrangement being counted twice because the particles can be permuted and such permutations are typically taken to have physical significance in this context. This counting is fundamentally important: according to Maxwell-Boltzmann statistics the probability of obtaining both particles in the left hand box, say, is ¼ and it is this assignment of probabilities that forms the heart of classical statistical mechanics and grounds the latter's underpinning of thermodynamics. In quantum statistics however, the 'one particle in each box' arrangement is only counted once; that is, to put it a little crudely, permutations are not counted in the statistics, so quantum theory is said to be 'permutation invariant' – we then obtain two forms: Bose-Einstein statistics, which allows both particles to be in the same box and hence for which the probability of both in the left hand box is now 1/3; and Fermi-Dirac statistics, which excludes both particles being in the same box and hence only allows the one particle in each box arrangement (see, for example, French and Krause 2006).

Let me say two further things about this piece of physics. First, the distinction between Bose-Einstein and Fermi-Dirac statistics manifested in the difference between the above probabilities is absolutely fundamental. Particles obeying the former – bosons – exhibit a statistical tendency to cluster together, something that is exhibited most strikingly in the phenomenon of 'Bose-Einstein condensation' (first produced in the laboratory in 1995 and for which achievement the Nobel prize was awarded in 2001; see http://en.wikipedia.org/wiki/Bose–Einstein_condensate) but the ability to pack bosons into the same state also gives us lasers – at the heart of so much modern technology of course!. Fermions, on the other hand, cannot occupy the same overall state (where this is taken to encompass all the relevant properties – so two fermions can occupy the same energy state but only as long as they have different spins, for example). Thus, this permutation invariance is what lies behind the famous Pauli Exclusion Principle, which in turn accounts for the Periodic Table and thus, contentiously perhaps, for chemistry. More generally, it is this behaviour that results in many of the well-known and 'everyday' properties of matter, such as solidity for example. Thus, fermions, such as electrons, are typically regarded as 'material', whereas bosons are taken to be the 'force-carriers' between such material particles.

Secondly, in mathematical terms, these two forms of quantum statistics correspond to different irreducible representations of the Permutation Group, which mathematically encodes this symmetry. (A group is a set of elements together with an operation that combines those elements, according to certain axioms, and a representation in effect renders the group more concrete by representing it in terms of (linear) transformations in some vector space, such as the Hilbert space of quantum mechanics.) The application of the mathematics of group theory to quantum mechanics was of major theoretical significance, both in terms of providing a further set of foundations for the theory and also simply as a way of yielding solutions to otherwise difficult to crack dynamical problems (see, for example, French 2014, chap. 4 and references therein). The bottom line as far as we are concerned here, is that in order to be physically acceptable, any Hamiltonian must commute with the permutation operator which combines the elements in the Permutation Group, where these elements represent quantum entities. This is a fundamental demand which crucially constrains our quantum theoretical description of an assembly of such entities and yields these mathematical representations corresponding to the two most fundamental kinds of particles, with radically different statistical behaviour.

However, it turns out that these are not the only kinds of statistics that are possible. If we consider more than two particles, other forms are compatible with the above constraint, forms that also correspond to different representations of the Permutation Group (for a summary of the relevant history, see French and Krause 2006; or for more general details, French 2014). These forms are generically known as 'parastatistics' and although they were known to the likes of Dirac back in the 1930s, it wasn't until the early 1960s that they came to be more fully explored as theoretical possibilities . Indeed, it was hypothesised at one point that quarks should be regarded as paraparticles. But this idea subsequently fell out of favour as the relevant statistical behaviour of the particles concerned was accounted for in terms of a new quantum number – ‘colour’ – together with standard quantum statistics, as outlined above, leading to the development of the theory of quantum chromodynamics as a theory of the strong nuclear force.

Now, there is much more to say, of course, but our aim here is just to illustrate how symmetries, as exemplified via the Permutation Group, impose fundamental constraints on theories, such as quantum mechanics. The question now is, how can dispositionalism accommodate these kinds of constraints?

4. The Dispositionalist Responds

One option is to take such symmetry principles to be nothing more than 'pseudo-laws', or false constraints, to be written out of our scientific world-view (Bird 2007, p. 214). As well as removing this obstacle to the extension of dispositionalism in general, it would also allow Mumford, for example, to pursue his eliminativism, as mentioned above. However, given the importance of such symmetry principles in modern physics and their role within the Standard Model in particular, I shall dismiss this response as tantamount to a counsel of despair (Livanios 2010; see also Cei and French 2014).

Another option might be to shift the ‘seat’ of the disposition, away from objects such as particles to, in this case, the world as a whole (see Bigelow et. al. 1992; also Bird 2007, p. 213). Now, I’ll come back to this issue of shifting the ‘seat’ (see section 5), but let me just remark here that it raises the further issue whether it is of the essence of dispositionalism that it be ‘object oriented’. In other words, must it be the case that only objects (however understood) can possess powers or dispositions? Insofar as dispositions arise from a second order analysis of properties (at least according to the Dispositional Identity Thesis) one might be inclined to insist that anything, object or no, that could be said to possess properties could then be said to have or possess dispositions. And if symmetries are seen as (relational) properties of laws, then one could argue that the latter could be regarded as the seat of the dispositions that give rise to symmetries. Whether such a view is still entitled to the name of dispositionalism is a further matter for discussion.

Here the issue is whether we can shift the seat to ‘the world’, still considered as an object. Now that latter point might be contested (see van Fraassen 1995), although monists (at least of a certain stripe; see for example Horgan and Potrc 2008) of course will insist that it is the only object! On such a view, the ‘usual’, local dispositions associated with properties, such as charge etc., would presumably be considered to be derivative of 'global' dispositions associated with the world-as-object. If one were unhappy with treating the world itself as an object, one might still retain the global character of the view within the kind of structuralist account that I favour (French 2014). I shall return to this in section 7, below.

But if we set such moves aside for now, the obvious worry is that grounding the dispositions to be associated with symmetries in 'the world', considered as an object in itself, seems ad hoc (Bird 2007, Livanios 2010.). Furthermore, and perhaps even more damagingly, it is not clear – on the Dispositional Identity Thesis – what the relevant property would be that would be decomposed into the appropriate dispositions. If that property is taken to be 'being the world' then we would have one property associated with myriad different dispositions. At the very least, the value of the dispositional analysis would appear to be cheapened by such a move. Alternatively, if the relevant properties of the world are taken to be those associated with the relevant laws, then one would have to wonder what the invocation of the world-as-object is doing when it is the laws that are the actual seats of the relevant dispositions. Finally – and again, this is an issue we shall return to – if it is the world (that is, the universe!) that is taken to possess, in whatever sense, the relevant dispositions, with the symmetries as manifestations, then one has to wonder what the associated stimuli could be. Clearly, in this case, shifting the seat of the dispositions but retaining an object-oriented approach undermines the S&M analysis.

Alternatively, one might try tweaking that S&M characterisation. Thus Chakravartty and Heil have suggested that the manifestations of dispositions may be relational in nature. Chakravartty (2007) has argued that the first-order causal properties of scientific objects by which we detect such objects, should be understood in terms of dispositions for specific relations which comprise the concrete structures about which we should be realists. Similarly, Heil (2005) argues that the manifestation of a disposition is a mutual manifestation of reciprocal disposition partners, so that rather than thinking of the S&M characterisation in terms of a chain, we should conceive it as yielding a kind of relational 'net', which might then be useful compared with Chakravartty's concrete structures. Heil offers the classic example of the dissolution of salt in water: we can see this in terms of the water being the stimulus for the dissolution of the salt or the salt being the stimulus for the manifestation of the saltiness of the water. As Chakravartty makes clear, this relational conception appropriately captures the relevant features of scientific properties and associated laws, although when it comes to the mutual manifestation of reciprocal disposition partners Reutlinger has dismissed this as 'just a fancy label for an uncontroversial fact' (Reutlinger 2013).

These are interesting moves, and certainly go some way towards accommodating various features of scientific theories (see for example Chakravartty 2013 and the discussion there). However, with symmetries regarded as constraints, or meta-laws, or more generally as relations between relations, it is difficult to see how they can be accommodated even by generalising the notion of a manifestation in the ways that Chakravartty and Heil suggest. The issue is how we get up to the 'next level' as it were, from manifestations as relational to symmetries as relations between relations.

One option, again, would be to shift the seat of the dispositions from the objects to the laws. However, it remains difficult to see how the S&M analysis would apply – again, what would be the stimuli in such cases leading the *laws* to manifest the relevant symmetries? There is a sense in which the reason the standard S&M analysis 'fits' an object oriented ontological stance is that with objects taken to be (minimally perhaps) spatio-temporally delineated in some manner, one can pretty straightforwardly conceive of external stimuli, such as other objects, or forces etc. In the case of laws, as standardly understood, it is difficult to conceive of such stimuli – if the laws are taken to be universal (which is why I specified 'standardly understood') what would be external to them? Objects don't affect laws and neither do forces – indeed, laws just don't seem to be the kinds of 'things' that could be affected that way (again, at least not as standardly understood). Of course, one can find non-standard views that take laws to be non-universal in nature or regarded as nomological entities that one would not normally take to be such (such as the wave-function in quantum mechanics, for example, something else we shall touch on again below). But again, it is difficult to see what would count as the relevant stimuli in such cases, leading to the manifestation of symmetries. One might appeal to some sort of 'multiverse' account and somehow argue that whatever it was that generated this particular universe with its associated laws and symmetries could count as the stimulus of the former generating the latter, but that would be to ride off into distant realms of speculation.

Another option would be to package up the laws and symmetries together, in the sense that the manifestation, under the S&M analysis, should be understood not just as relational, in the way that Chakravartty and Heil suggest, but as second-order relational in that it includes the relations between relations that come to be categorised as symmetries. In other words, the disposition yields the relevant law and symmetry as a bundle. An attractive feature of such a proposal is that it might explain why symmetries and laws are bound so tightly together – they are so because they both derive from the same source, namely the relevant disposition.

However, at the very least this suggestion needs fleshing out to show how it would actually pan out within the dispositionalist framework. Again, consider the S&M analysis: at the heart of Vetter's criticism of it (see above section 2, pp. 6f.) is the claim that the best that we get is a bunch of instances of the form 'if we bring a charge up to the test charge at such-and-such a distance, it experiences such-and-such a force (or acceleration)' and so on. What we don't get is Coulomb's Law itself, or at least not as standardly understood as a universal generalization. We are then left with an explanatory gap, something which alternative accounts of laws can exploit (see, again, French 2014, chap. 9 for discussion).

If we can't even get to laws from instances of S and M, then it remains completely unclear how we get up to the next level, to symmetries. Even if one were to insist that the appropriate manifestation is not just the experienced force, or acceleration, but the force or acceleration as conditioned by what we come to identify as the associated symmetry (in the case of charge, represented by the U(1) group), this still does not take us 'up' to the universal nature of such symmetries, for the same reasons as Vetter identifies.

There is also the issue of whether this analysis, even if successful, could capture the way in which symmetries act as constraints. Insofar as this is discussed, it is typically taken to be a 'top-down' kind of constraint; indeed, Wigner understood symmetries to be 'meta-laws' in a sense. Now of course to insist on that 'top-down' nature would be to beg the question against dispositionalism, in just the same way as insisting that laws govern properties would. As Mumford (2006) has astutely noted, the latter conflicts with the reductive, bottom-up approach of dispositionalism and setting aside the issue of whether his eliminativism can be applied to symmetries as well, one can at least acknowledge that this constraining feature of symmetries must be reconceived in this context. In essence, the dispositionalist must maintain that it is of the nature of the dispositions in terms of which charge, for example, can be analysed that the laws that 'flow' from or supervene upon them are then constrained by these further features. Setting aside Vetter's concerns as to whether this supervenience even holds in the first place, the constraint would have to be conceived of as bound up in the manifestation, so that what appears to be top-down is actually exercising itself from the bottom up, as it were.

In the case of symmetries associated with particular properties, such as U(1) and charge, or SU(2) and isospin, that seems a possible way forward at least, although, as I have said, it has yet to be developed in any significant form (also see Bauer 2011) and it may be metaphysically more straightforward to simply drop the S&M analysis entirely. I shall return to this idea in section 7. But what about permutation symmetry? This seems to impose a top-down constraint that applies ‘across the board’, as it were, and cannot be folded into any dispositionalist reduction of a particular property. Or can it?

5. From Statistics to Spin

It turns out that there is a connection between the statistical behaviour of elementary particles and the quantum property known as ‘spin’ (enfolded within the extension of dispositionalism by Mumford, for example, as we have seen): particles that obey Bose-Einstein statistics have integral spin and particles that obey Fermi-Dirac statistics have half-integral spin. This connection is underpinned by the ‘Spin-Statistics Theorem’, a proof of which was famously given by Pauli, using considerations which draw from Einstein’s Special Theory of Relativity. So, if we see spin as that property whose identity is given in terms of the disposition for particles to behave in a certain statistical way, we might be able to bring permutation symmetry within the dispositionalist purview.

Now, of course, spin is an interesting property in that it has no classical analogue. Although it is associated with the ‘intrinsic’ angular momentum of the particles and has the same units as classical angular momentum (the Joule-second), one should not think of the particle as literally spinning like a little top (the ‘direction’ of the spin is not like that of a classical vector quantity for example). Nevertheless, the recent exploitation of spin in electronic devices – leading to the field of ‘spintronics’ (see: https://en.wikipedia.org/wiki/Spintronics) – establishes it as a measurable and technologically usable property – just like charge – that should in principle be capable of being understood from a dispositionalist perspective.

However, even granted all of that, it turns out that symmetry re-enters the picture in a way that undermines the attempt to bring spin within dispositionalism’s grasp. One of the virtues of Pauli's proof of the theorem is that by calling on relativity theory it meshes with what is generally understood to be spin's relativistic nature. And that nature can be summed up in the pithy statement that the property effectively 'drops out of' another group – the Poincaré group, which is the symmetry group of relativistic field theory. More specifically, it is the group that applies to Minkowski space-time – the space-time of Special Relativity – and it turns out that the irreducible representations of *this* group yield a classification of all elementary particles, with these representations indexed or characterised by mass and spin (the invariants of the group). Thus, even if we were to 'ground' the particle statistics generated by Permutation symmetry in the property of spin, and analyse the latter dispositionally à la charge, that analysis would still have to deal with symmetry, now in the guise of the Poincaré group.

Now, there are two things to note here. First of all, there is the issue of how we should regard spin qua property. If we adopt the apparently plausible view that our metaphysical analysis of the nature of a given property should at the very least touch base with the theoretical and experimental practices by which we gain epistemic access to that property, then we need to confront the fact that although the rise of spintronics demonstrates the causal impact of spin, its existence is effectively guaranteed by the relevant symmetry as expressed via the Poincaré group. Thus as Morrison emphasises, in her extensive study of the history and physics of spin, '[o]ur current understanding of spin seems to depend primarily on its group theoretical description' (2007, p. 552). How that group theoretic feature should be captured ontologically remains a contentious issue – Morrison herself argues that it implies that spin should be regarded as a 'hybrid' mathematical and physical property (2007; for criticism see French 2015). I shall not pursue this issue here but simply note her point that: '[p]art of the difficulty with attempts to generate a physical notion of spin concerns the way the electron is pictured in the hydrogen atom as a quantum mechanical object' (Morrison 2007, p. 554). Thus the involvement of symmetry via the group theoretic characterisation of spin suggests that we should drop the picture of it as a property that is associated with objects in the usual way.

Secondly, one can again make the case that the relevant symmetry should be seen as a kind of 'meta-law' or top-down constraint. Thus Lange (2013) has argued that such a characterisation explains why the Lorentz transformations would still have been true, even if the relevant force laws had been different. The former have a greater modal strength than the latter in the sense that we can conceive of relativistic worlds in which the symmetries hold (otherwise they wouldn't be relativistic!) but the relevant laws don't. Thus the dispositionalist, seeking to escape the constraining effect of Permutation Symmetry by appealing to the Spin-Statistics Theorem, finds herself hopping out of that particular frying pan and into the fire!

Nevertheless, granted that spin should be seen as a consequence (in some sense) of space-time symmetry, there might still be options available to the dispositionalist. Let us explore them again *via* the question of what the 'seat' of the relevant disposition might be.

6. Seating Spin

Thus the first option would be to take that seat to be the particle, and to regard spin as associated with the disposition that manifests Poincaré symmetry, where the manifestation here is obviously relational, in the manner articulated by Chakravartty 2007 and Heil 2005 perhaps. Now this option would appear to be blocked by what we have just said regarding the way spin 'drops out' of the symmetry. However, one could try to turn the explanatory arrow the other way around and insist that spin can be associated with a certain kind of dynamical behaviour of particles that we then codify in terms of the Lorentz transformations and the Poincaré group. This would be to reject the latter as a constraint and to argue that insofar as it is taken to represent the structure of relativistic space-time, that structure, as represented geometrically, is essentially a manifestation of the dynamical behaviour of the particles and thus of the force laws.

This would appear to be quite a radical line to take but it has been taken, most notably by Brown (2005). He argues that the structure of relativistic space-time should indeed be seen as '… a codification of certain key aspects of the behaviour of particles' (ibid., pp. 24-25) and the dispositionalist could hitch her wagon to Brown's account and argue that spin, as a property, features in certain dynamical laws which manifest or express Lorentz invariance as a result of which relativistic space-time has the structure that it does. However, the nature of the explanation then becomes unclear and in particular how it is that the symmetry, qua a feature of the relevant laws, results in the relevant geometric structure of space-time (see Skow 2006). And of course the dispositionalist still has to account for that feature within the framework of the S & M characterisation. Finally, as a possible 'seat' of these obscure dispositions, particles themselves are notoriously problematic in this physical context, despite physicists' use of the term, with a number of well-known arguments to the effect that the notion of particle, as usually conceived, cannot be sustained within relativistic quantum field theory (see, for example, Bain 2011).

An alternative option would be to shift to a field-theoretic ontology and insist that it is the quantum fields that offer an appropriate seat for the dispositions, with spin understood as a field property. Now insofar as fields are global entities, we might see this as akin to the previous option of taking 'the world' as this seat, with the crucial difference that they may be fewer reservations about the appropriateness of fields in this regard as compared to 'the world'.

Of course, there is then the further issue of the relation between the field *qua* global entity and relativistic space-time, structured via the Poincaré group. Two further options arise, depending on how one understands fields (see French and Krause 2006, pp. 51-64). One is to conceive of them as global substances, spread out, jelly-like, across space-time. In this case, if the field is to be the seat of the disposition in terms of which spin is understood such that it can be associated with the Poincaré group, something is going to have to be said about the relationship between that global entity and space-time; however, it is not clear what. The alternative – and perhaps more widely held – option is to understand fields in terms of assignments of field quantities or properties to space-time points (where these assignments will be appropriately 'smeared' in the case of quantum fields). In this case, the field itself is not substantival but simply represents the way in which properties are distributed across the whole of space-time.

Following this latter option obviously shifts the seat of the relevant dispositions from the field *per se* to space-time. Again, there are further options. One is to take the relevant seat to be space-time *qua* entity as a whole, bringing us back towards a monistic position with similar problems in ascribing property based dispositions on a global scale. Recall: we are not ascribing Poincaré symmetry *qua* disposition to space-time as a global entity but rather are so assigning spin and other properties as expressed in the usual force laws from which the symmetries will emerge in some fashion. Without the form of ontological pointillism that particular objects provide (just to alliterate a little) it is difficult to make sense of the manner in which these various dispositions can be supported. And there is still the problem of articulating any sense of external stimulus in this context.

Fortunately there is the further alternative of taking space-time to be ontologically composed of a manifold of points, which supports various structures, including that expressed via the Poincaré group. The field assignments are then to these points or regions composed of them. And the seat of the relevant dispositions would be these particular space-time points themselves. One might then be able to elaborate a physics-based form of dispositionalism according to which both space-time structure and properties such as spin can be regarded – via the mediation of field theory – in terms of dispositions possessed by the points of relativistic space-time.

Now, of course, this would be to commit dispositionalism to a form of substantivalism with regard to space-time, which many have found problematic, as is well known (for a useful survey see Norton 2015). Certainly, as objects, in a sense, the points of Minkowski space-time are not really on a par with the kinds of objects that dispositionalists usually latch onto. Although these points, or the manifold that they constitute, support the kinds of structures indicated above and thus in a sense (disputed by the likes of Brown, of course) could be said to causally constrain physical processes (so the 'light-cone structure' prevents processes from accelerating past the speed of light), there is a lack of causal reciprocity in that the space-time structure itself is not affected by these processes.

This reciprocity is restored in General Relativity, but unfortunately, in that context, there are well-known arguments that have been taken to rule out the above straightforward ontological understanding of space-time as constituted by a manifold of points supporting various structures (namely the so-called 'hole' argument which shows that on such an understanding the points can be shifted about, creating a 'hole' which is compatible with all the relevant dynamics, leading to a kind of inadmissible ontological indeterminacy; again for an accessible introduction, see Norton 2015). Those of a substantivalist inclination have responded to such arguments, in particular noting the assumption that the points have a kind of primitive identity and that the arguments dissolve if this is dropped (Pooley 2006). According to the 'sophisticated substantivalism' that results, the space-time points become no more than placeholders to support the relevant structure that embodies the physics (so again we move towards a kind of structuralism).

At this point, the question becomes: how can that which is only a placeholder for relevant space-time structure(s) be regarded as the seat of the dispositions from which flow (somehow) or on which supervene (again, somehow) the symmetries constituting that structure? At best this particular seat is very thin indeed.

But things get even worse for the dispositionalist. One might argue that these space-time symmetries are, at least, physically implementable: one can translate objects through space, or rotate them or give them a swift kick and thus a boost (and if the kick is hard enough, the boost may be significant enough to warrant deployment of the Lorentz transformations!). Thus one could form the following subjunctive conditionals:

If *P* is a real (determinate) physical property of *x* and were *x* to be translated through space, then *x* would remain *P*

If *P* is a real (determinate) physical property of *x* and were *x* to be rotated through space, then *x* would remain *P*

.

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If *P* is a real (determinate) physical property of *x* and were *x* to be given a Lorentz 'boost', then *x* would remain *P*

Taking them in conjunction, one could then form the more general subjunctive conditional: If *P* is a real (determinate) physical property of *x*, and were *x* to be Poincaré transformed, then *x* would remain *P* (see McKenzie forthcoming).

Thus one can envisage this kind of symmetry being shoe-horned into the S&M analysis by taking the translations, rotations and boosts to be the stimuli and the invariance of the given property as the manifestation. This would then mesh with Brown's approach to relativity theory, indicated above, whereby the focus is on the objects, or more generally, systems and their dynamical behaviour, with the relevant symmetries arising out of that.

However, concerns arise with regard to the subjunctive element in the above formulations: what does it mean to say '*were* x to be Poincaré transformed'? It seems straightforward to understand how an object might or might not be translated through space or boosted or whatever, but there's a jump from this to a similar understanding about subjecting the given object to the Poincaré transformations, *where these are* *understood to be representations of certain features of the structure of space-time*. With the (local) space-time understood to be Minkowskian, talk of *x* being 'transformed' seems to attribute power inappropriately – as if *x* might not be. But given that *x* is situated within this particular space-time structure it is not as if the Poincaré symmetry can be turned off somehow; in other words, from this perspective, it is occurrent. Of course this is the perspective of the standard, non-Brownian view, but even if one were to adopt Brown's account, there are symmetries that are not physically implementable in this manner.

7. Internal Symmetries

These are the so-called 'internal symmetries' (some of which have already been mentioned with regard to the Standard Model). So, if one kind of particle, defined by a certain set of quantum numbers, evolves or interacts in accordance with some Hamiltonian, then there is another kind of particle, defined by a different set of quantum numbers, that also does so. Thus families of particles can be formed, or 'multiplets', associated with different groups and representing different forces, as indicated earlier:

Electromagnetic: U(1)
Weak nuclear: SU(2)
Strong nuclear: SU(3)

And as was noted above, the combination SU(3) x SU(2) x U(1) forms the mathematical basis of the Standard Model.

So, in the case of the weak nuclear force, responsible for radioactive decay (as we have seen, explicitly embraced by the dispositionalist), the associated quantum number is known as 'weak isospin', which is conserved in interactions involving this force, with the relevant group SU(2). Isospin was originally introduced in the context of the strong nuclear force as a way of accounting for certain symmetries associated with the then newly discovered neutron. In particular, it was noted that the mass of the neutron was comparatively close to that of the proton and the strength of the strong interaction did not depend on whether the particles were protons or neutrons (the fact that the masses are not the same means that the symmetry is broken). Thus, ignoring the mass difference, one could treat the proton and neutron as two different states of the same entity, the nucleon, each with different isospin. Isospin was originally modelled on the mathematical representation of spin and was subsequently extended to quarks (the up and down quarks also have very similar masses), thus requiring an enlargement of the associated group to SU(3).

Now, what is important is that the transformations represented by these groups do not ‘take place’ in physical space, as in the case of the Poincaré group; rather they are represented via highly abstract mathematical spaces that have no physical counterparts. In particular, these ‘internal’ symmetries are not physically implementable and thus no subjunctive conditional can be formed as in the Poincaré case. In effect, the symmetries are always ‘on’ and hence, again, are occurrent (see, again, McKenzie forthcoming). Now, even if we were to accept the above shoe horning of the Poincaré group, *these further symmetries that lie at the heart of the Standard Model simply cannot be accommodated by the S&M picture*.

Enough already. Let’s recall that we started off down this branching path in an attempt to avoid the constraint imposed by Permutation Symmetry by crossing the bridge offered by the Spin-Statistics Theorem and grounding the statistical behaviour of particles in their spin. But spin in its turn appears to be grounded in a further symmetry, as represented via the Poincaré group. Attempts to ground that symmetry in some further particular, either global or local, appear to be fruitless and the Stimulus and Manifestation account looks simply inappropriate when it comes to these space-time symmetries but even more so when we take on board the ‘internal’ symmetries of the Standard Model. So perhaps we should just acknowledge the constraining nature of these symmetries and attempt to adapt dispositionalism accordingly. The problem, as we have repeatedly noted, is not just with regard to what would count as the seat of the disposition – we seem to have reached the point where the best we can say is that the space-time structure itself is that seat, in some sense – but also with the Stimulus and Manifestation framework within which dispositionalism is standardly presented. Again, even if we can articulate a sense in which these constraining symmetries can function, metaphysically, as seats of dispositions, it is unclear, or perhaps even impossible, to see how they can be appropriately stimulated!

Perhaps, within the framework of the ‘toolbox’ approach, as introduced at the beginning of this essay, there are devices or moves in recent developments and extensions of dispositionalism that we can appropriate to help capture the above kinds of symmetries and thereby enfold them within a modal metaphysics.

8. Taking up some Tools

Thus Mumford and Anjum have reconceived the notion of a stimulus as the pragmatic designation of a contributory power, where such powers should be regarded in terms of *sui generis* tendencies (Mumford and Anjum 2011). Powers, on this view, should be seen to be not so much stimulated as 'unleashed'. Consider the example of a pool of petrol in an oxygen-rich environment: the spark that ignites the conflagration should not be seen as a stimulus per se but as a further contributory power. A given effect or manifestation may then be the result of many such powers operating at once, and Mumford and Anjum give an analogy with the vector addition rule for forces (for criticism see Glynn 2012 and Pechlivanidi and Psillos's contribution in this volume). Obviously such an analogy is going to be inappropriate in the case of symmetries, since these are not 'force-like' and not subject to the same kind of rule, but more importantly, it is difficult to see what the contributory power would be in the situations we have considered here or how a symmetry could be regarded as 'unleashed'.

Cartwright also eschews the standard dispositional analysis and in discussion has suggested that the 'seat' of the relevant powers could be seen as the quantum state itself, which encodes the properties, laws and symmetries in one package. One can see a similar idea in Esfeld et. al.'s recent work where they argue that the particle configuration as a whole instantiates the dynamical, dispositional property that determines the temporal development of the system and which is represented by the universal wave function (Esfeld et. al. forthcoming). Again, there is no question of there being any stimulus or external power involved – things simply unfold according to one disposition that enfolds everything. Now there is a lot to say about this sort of suggestion but the immediate worry is that it seems an ad hoc response and, furthermore, loses whatever advantages the dispositional account enjoyed in terms of metaphysical explanation via the S&M analysis.

Here's a further suggestion, in Cartwrightian vein: Hüttemann argues that all laws should be regarded as default laws, in the sense that they 'tell us what happens if nothing interferes'. Causes should then be understood as interfering factors or antidotes that explain why the dispositions ascribed by the laws fail to be (completely) manifested. Such a view allows for partial manifestations, as in the example of a crystal, for which the presence of an impurity would be the interfering factor. Thus, even if there is no complete manifestation, we can still have evidence for a particular disposition (Hüttemann 2009). On this view, the relevant dispositions are continually manifesting and one might regard symmetries likewise. Indeed, one could then construe the kinds of 'internal' symmetries involved in the Standard Model as only partially manifested due to symmetry breaking (as in the case of the mass differences between the 'up' and 'down' quarks which breaks the SU(3) symmetry). However, there are no causal interfering factors in this case so it is not clear that as it stands this sort of approach could be said to apply to symmetries. Of course, one might envisage an extension of this approach that drops the causal aspect but even so, it remains unclear what might count as the relevant interfering factor.

One might have similar worries about Vetter's suggestion that we should drop the S&M analysis entirely, particularly the S side, and take dispositions to be individuated by the manifestation conditions alone (Vetter 2014 and 2015). Of course, as she recognises, this effectively divorces her account from the usual counterfactual analysis (the clue is in the title of her paper!). It also thereby again loses the apparent advantages of standard dispositionalism in explaining or grounding causation and the necessity of laws. However, Vetter argues that these should be seen as a separate 'ingredient' that may or may not be part of the manifestation, depending on the circumstances and the nature of the disposition. More positively she draws on the ways we talk about possibility in our everyday language to argue that dispositional ascriptions are naturally paraphrased via expressions of possibility, the localised counterpart of which is potentiality (2015, p. 23). Thus the relevant sense of modality is best characterised (to a first approximation) by '*x* can *M*' (where this should be understood as graded and context-sensitive).

As Vetter herself notes, by losing the counterfactual analysis and dropping causation, this account appears to be precluded from being applied to scientific properties. But of course, as we all well know, causation is problematic to say the least at the level of fundamental physics. Indeed, Nolan, for example, has sought to accommodate this by arguing that certain dispositions are non-causal and drawing on features of quantum physics such as the infamous EPR correlations, particle creation, radioactive decay and so on (Nolan forthcoming). No doubt, as he would acknowledge, more needs to be said here. So, although radioactive decay and particle creation appear to be non-causal and random, they fall within the framework of the Standard Model, as already noted, and are subject to the kinds of considerations we have indicated above. As for the EPR correlations, although it is certainly true that they face well-known problems being accommodated within a causal framework (Bell's Theorem comes into play here), it is certainly not at all clear how they might be regarded in terms of, or a as a result of, some kind of disposition. Consider: Teller famously argued that one could give a metaphysical explication of these correlations in terms of non-supervenient relations (Teller 1986). If the seat of the relevant disposition is taken to be the quantum objects – perhaps the most obvious choice – then the usual account of the relational manifestations 'flowing from' or 'supervening on' these dispositions is going to be blocked. Furthermore, the very concept of 'object' faces considerable metaphysical problems in the quantum domain (French and Krause 2006) and as in the space-time case, the best we can hope for is a 'thin' notion of object as placeholder for the relevant structures, or in this case, the relevant correlations – and again that seems a very weak peg on which to hang one's dispositional hat!

Returning to Vetter's account, she herself acknowledges that it cannot be applied to fundamental properties in physics. But I think she is being too quick here. Certainly, it cannot be applied to classical properties, where the standard dispositional analysis gets some traction. But we've already seen that this analysis needs to be given up and, in particular, the characterisation in terms of stimuli abandoned. Suppose we were to follow her suggestion, drop the S, allow for laws and symmetries to be aspects of the manifestation of a graded kind of possibility? Vetter still retains objects as the seat of her localised possibilities, or potentialities, but let us drop those as well, since they are too thin to bear the metaphysical weight. Instead, I would urge that we should take as our seat that which is doing all the physical work, namely the relevant physical structure – that of Minkowski space-time in the case of Special Relativity and that as presented via group theory in the Standard Model (French 2014; McKenzie 2013). Then we have something like this: our seat, not of dispositions (since without the conditional analysis we can hardly call this a dispositional account) but of possibility, is the physical structure, with no relevant stimuli, no S&M analysis and thus no subjunctive conditionals. However, there is individuation via the relevant manifestation (including, in a reversal of the usual metaphysical dependence, properties like spin, mass …) and an understanding of Vetter's '*x* can *M*' can be given as 'the structure contains certain possibilities', or possesses certain potentialities. The example would be that of Permutation Symmetry, which contains more possibilities than the Bose-Einstein and Fermi-Dirac statistics that we observe in this the actual world, and thus there is the potential – fleetingly realised in the 1960s – for non-standard statistics to be manifested

(Vetter herself prefers what she calls a ‘piecemeal’ approach and rejects this kind of ‘catch-all’ view (2015, pp. 259-263), although I would offer the above as the ‘new conception of the world as a structured object’ (ibid., p. 261) that she feels the catch-all view must provide if it is to be plausible).

Elsewhere I have claimed that we have to accept a kind of primitive modality associated with physical structures of this form (French 2014) but as with all invocations of primitiveness, such a conception seems to suffer in comparison with the richer metaphysical details of an account such as dispositionalism. However, dispositionalism, at least as standardly characterised in terms of the S&M analysis, seems to be ruled out by modern physics and some may see this as a further indictment of current metaphysical reasoning. Yet that would be too quick, as the latter may still provide the tools by means of which we can accommodate symmetries and the like. I’ve indicated one such tool, namely Vetter’s notion of ‘potentiality’, but there are others which may also be deployed, offering some hope for a naturalised metaphysics that does not require us to build new frameworks from scratch. Perhaps by drawing on these metaphysical tools, we can indeed redress the balance and arrive at a view that can accommodate quarks as well as vases.

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