In No Categorical Terms: A Sketch for an Alternative Route to a Humean Interpretation of Laws

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Abstract

Philosophers of science will be familiar with the 'canonical' debate in metaphysics over the modal status of natural laws. In this debate, the Humean faction adopts a world-view in which the fundamental properties are *categorical*, from which it follows that natural laws are metaphysically *contingent*. The Anti-Humeans, on the other hand, adopt an account in which the fundamental properties are *essentially dispositional*, which entails that the laws are metaphysically *necessary*. In this paper I will argue that the basic terms in which this debate is conducted are woefully out of date from a scientific point of view. I will further argue that once we rectify this the categorical properties that the Humean's contingentism about laws is built upon no longer have any place – nor that there is much room to accommodate a contingentist account of laws in any case. The first moral to draw from all this is that Humeanism understood *a la* the canonical account is more or less dead in the water. But since the basic terms of the canonical dispute are long past their sell-by date anyway, we need not take that to imply that Humeanism is dead *tout court*. I will argue that an interpretation of laws compatible with Humean strictures is in fact still very much in the offing: it cannot, it appears, be a Humeanism built on the ediface of categorical properties, nor even one that commits to contingentism; but I think we can claim it as a Humean approach to laws nonetheless.

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1 Introduction

A debate over the modal status of natural laws and physical properties has been raging in the literature for decades, and the factions are by now familiar. On the one hand we have the *Humeans*, primarily represented by Lewis and his followers, who commit to the idea that the fundamental properties are categorical in character and the laws of nature metaphysically contingent (see, e.g., Lewis (1983); Loewer (1986); Cohen and Callender (2009)). On the other hand we have the *Anti-Humeans*, such as Ellis and Bird, who believe that the fundamental properties are essentially dispositional and the laws metaphysically necessary (see Ellis (2001); Bird (2007)). As the titles suggest, what ultimately divides the two factions is their attitudes to Hume's famous dictum that there are no "necessities in nature" – that is, no necessary connections between distinct existences that cannot be reduced to those of mathematics or logic.

This binary opposition in modal disputations will be familiar to many of us (as a first approximation at least). For brevity, I will designate the debate between these two sides, so characterized, as the 'canonical debate'. Despite its familiarity and prominence, however, I want to argue that there are profound problems afoot in the presuppositions made by each side in this debate, and in particular that the basic terms in which it is conducted are woefully out of date. Both parties, after all, have pretensions to giving an account of *fundamental* laws and properties, and both of these are obviously the sort of thing that will be described by fundamental *physics*, assuming that they can be described anywhere at all.[1] But the impression given in the major works of this debate is that Coulomb's law represents the cutting-edge of modern physics, which it emphatically does *not*. Nor is this a merely technical and metaphysically uninteresting point, made by another philosopher of physics lamenting the lack of engagement by contemporary metaphysicians with contemporary physics; for on the contrary, as we shall see, incorporating concepts basic to current fundamental physics can change the modal landscape quite dramatically, and naturalism demands of us that the structure of our metaphysical debates must change along with it.

In the course of arguing for that conclusion, my focus will be kept on the fundamental *kind* properties throughout – that is, the state-independent properties such as charge, hypercharge, isospin, etc. that we take to define the various fundamental particle kinds.[2] The critical part of my argument will proceed in two stages:

> firstly, I will argue that the canonical debate over nomological modality assumes an account of natural law that is not appropriate for elucidating either fundamental properties or fundamental laws, and
>
> secondly, if we move to a more realistic account of fundamental laws, then it is no longer

[1] That the debate is principally over *fundamental* properties is emphasized in Bird *op. cit*; see, e.g., Section 3.3 and the discussion of 'finkish dispositions'.

[2] The property of mass requires a separate treatment, as my discussion will be limited to so-called *internal* symmetries throughout; it is essentially because we do not currently possess a working quantum-theoretic treatment of gravity that accounts for this exceptional status. A longer paper would expand upon the relevant distinctions in a fuller way than I can here.

clear that there is any place for categorical properties in our metaphysics (or at least not as such properties are standardly conceived), nor that one may regard the fundamental laws as contingent in anything but a tightly circumscribed sense.[3]

Since the canonical Humean package is defined by a commitment to the categorical nature of fundamental properties and the contingency of natural laws, the tempting conclusion to draw from all this is that Humeanism is dead in the water. Surprising as it may at first seem, however, I will argue that such a conclusion would be too rash. In particular, I will argue that modern physics makes space for a view in which necessitarianism about laws can be combined with a broadly Humean outlook; it is a Humeanism that must jettison its commitment to categoricalism, granted, but I think that we can claim it as a viable Humeanism about laws nonetheless.

To begin, then, I will outline in a little more detail what I take the canonical debate over laws, properties and modality to consist in. Once that is in place, I will articulate the problems I perceive to be inherent in the act of appealing, in the fundamental physics context, to the notion of categorical properties, and also in maintaining that the fundamental laws can be regarded as metaphysically contingent.

2 The canonical account of laws, properties and modality

Painting things in as broad brushstrokes as possible, there are two categories of modal accounts of laws to be found in the literature. On the one hand we have *contingentist* accounts, according which the laws of nature consist of metaphysically contingent connections between properties. The majority of contemporary adherents of this view adopt some version of Lewis' 'sophisticated regularity' view. On the other hand we have *necessitarian* accounts, according to which the connections between properties are regarded as metaphysically necessary – or at least, metaphysically necessary in the sense that properties obey identical laws across any and all possible worlds in which they are instantiated.[4] This dispute over whether natural laws are contingent or necessary is the bone of contention regarding laws in the canonical debate.

The next thing to note about the canonical debate is that each of these modal accounts of laws is *grounded* in a prior modal conception of properties.[5] Thus, on the one hand, necessitarians about laws typically assume an account of fundamental properties according to which they are 'essentially dispositional'. Since part of what it is to be an essentially dispositional property is to *imply* instances of laws, it follows on this view that a given species of fundamental particle, defined by a given set of fundamental kind properties, can act in accordance with *one and only one* law across all possible worlds in which tokens of it are instantiated. It is thus this

[3]In particular, I will argue that there is reason to think that the variation permitted is limited to the values of numerical constants only.

[4]Such a conditioned necessity is sometimes called 'weak' metaphysical necessity.

[5]As Earman and Roberts (2005) point out, this has the result that both factions are committed to a thesis in which the laws supervene on the fundamental property basis, and as such don't strictly speaking 'do any work'. See also Mumford (2004).

modal conception of properties that necessesitarians typically take to *account* for the fact that the laws are metaphysically necessary. On the other hand, contingentists about laws reject this view of fundamental properties, and as such also reject the idea that the kinds instantiating such properties bring in their wake a unique law. They rather endorse an opposing view in which fundamental properties are deemed 'categorical', and it is this categorical conception of properties that undewrites the idea that a given kind of particle could behave differently.

In what I call the 'canonical account', then, contingentism about laws goes hand in hand with categoricalism about properties, and necessitarianism about laws with dispositional essentialism. The package consisting of the first pair of commitments defines the *Humean* perspective on the fundamental laws and properties in the canonical account; the package consisting of the second pair defines the *Anti-Humean* point of view.[6] Since it is in each case a modal commitment regarding properties that grounds the corresponding modal stance on laws, the modal characterization of properties is really the fulcrum about which the canonical debate turns. This circumstance is reflected in the fact that so much of the ink spilled by Anti-Humeans concerns the proper articulation of essentially dispositional properties.

However, and while what exactly is involved in the concept of an essentially dispositional property has been discussed at great length, I think we have to agree with Mumford when he says that 'it is quite difficult to find, anywhere in the literature, a specification of what exactly is intended by "categorical property"' (Mumford (1998), p. 75). But it is obvious that without *some* such specification, the precise connection between categorical properties and the contingentist interpretation of laws can only remain murky, and with it the content of the Humean package as a whole. If one looks at the literature, what one finds in lieu of a precise characterization is that a variety of strategies are deployed to at least gesture at what is intended here. One finds categorical properties characterized, for example,

> in *metaphorical* terms, as those that don't 'look outward to interactions', or as those properties that don't 'point beyond' themselves; those that are 'self-contained... keeping themselves to themselves' (Armstrong (1993), p. 69; p. 80); or alternatively

[6] A couple of points are due regarding my designation of the above as the 'canonical debate'. (1) The first point is that, of course, not every protagonist in the literature on natural modality fits neatly into one or other of the categories just defined. Armstrong's view, for example, commits to both categoricalism about properties and contingentism about laws, but nonetheless endorses primitive necessary connections (albeit 'soft' or 'contingent' ones) between the properties involved in laws, apparently in conflict with Hume's dictum (Armstrong (1983)). As such, his position is often taken to lie somewhere between the two above positions, and designated as 'semi-Humean' (see for example Bird *op. cit.*, Sec. 1.1). However, given the shared commitments between Armstrong and the Humean position as defined above, my criticisms of the latter position will apply to Armstrong's account too. However, the relevance for Armstrong's concerns of my conclusion regarding the vindication of Hume's dictum is something I cannot discuss here. (2) Another prominent party in this debate that may not seem to fit neatly into above-defined categories is Mellor. Mellor is inclined towards a contingentist view of laws (see e.g. his (2000), p. 770 – but note the qualification on p. 772), and yet is ambivalent as to whether properties should be thought of as categorical (see Mellor (2003), p. 231). It therefore appears that one can be a Humean about laws without committing to categorical properties. However, Mellor's ambivalence about categorical properties seems to owe largely to the lack of clear and consistently-used criteria for what 'categorical' means in the first place, and I will have something to say about this in the next section.

in explicitly *nomological* terms, as those properties that are 'free of nomic commitments' (Carroll (1994), p. 8), hence as those that do not 'necessarily involve laws' (Loewer *op. cit.*, p. 200); or sometimes

in *spatiotemporal* terms, namely as those properties such that 'their instantiation has no metaphysical implications concerning the instantiation of fundamental properties elsewhere and elsewhen' (Loewer *op. cit.*, p. 177).[7]

There thus seem to be a number of ways of approaching what is meant by 'categorical property'. Greater variety does not equate with greater clarity, however, and it would certainly be nice if what is meant by 'categorical' in this context could be sharpened up. Let us therefore try to do so now.

A strategy frequently adopted to convey in concrete terms that which is meant by 'categorical' is that of simply *conveying by example* the implications that such properties have for some familiar natural laws. So, for instance, it is often cited that on the categoricalist view charged particles are not bound to obey Coulomb's law, and in particular that 'negative charges might have been disposed to repel positive charges, or some other relation may have held between them' (Bird *op. cit.*, p. 68). Thus part of what is meant by calling charge 'categorical' is that

$$F(x,y) = +C\frac{q(x)q(y)}{r^2(x,y)}$$

– Coulomb's law with a sign flip – represents a possible law. Similarly, it has been said that if charge is categorical then 'the contribution of distance might have been such that an inverse cube law held' instead of the Coulombic inverse square, so that

$$F(x,y) = -C\frac{q(x)q(y)}{r^3(x,y)}$$

is also taken to represent a possible law on this view (Armstrong (2005), p. 313).[8] Now, the first thing to point out about this strategy is that the specific examples offered in the literature of alternative laws are typically rather conservative in how they differ from the actual laws – consisting in these cases just of a sign flip and unit increase of power in the denominator respectively. The second thing to point out is that such discussions tend to be utterly silent on what *principles govern* how, and how considerably, the actual laws may be tinkered with so as to generate acceptable other-worldly alternatives such as these, and thus also to be silent on the range of nomic possibilities that are open to a given property. Insofar as the concept of categorical properties is to be articulated in terms of this variation, then, it is obvious that the concept can only remain unclear pending some statement of what principles limit how a law can be tinkered with so as to generate possible alternatives. However, given that such

[7]Another way to characterize categorical properties is in terms of quiddities: properties will be said the be categorical if their identity is exhausted by their quiddity. However, since it is this lack of any other features that implies each of the above designations, problems for any of the above characterizations will also be problems for this one.

[8]Armstrong's example in fact concerns mass and the law of gravity, but the claims are perfectly analogous.

properties are explicitly regarded as 'free of nomic commitments', perhaps we should take this absence to indicate that it simply goes without saying that there *are* no such principles (or at least no non-trivial ones), in spite of the somewhat conservative nature of the stock examples of allowed variation. But if *that* is the case, then we can improve upon this strategy of conveying by example and in a piecemeal fashion what is meant by 'categorical' by moving to a more general – and thus more definitive – characterization in the following way.

Recall that the example just looked at was that of Coulomb's law. This law is a paradigmatic example of a *classical* law, and as such of a *functional* law. That is, Coulomb's law is a law of the form

$$a(x) = f(b(x), c(y), d(x, y)),$$

where $a(x)$, $b(x)$, $c(y)$ and $d(x, y)$ are real- (or real vector-) valued functions representing the determinable physical properties A B, C and the relation D, and f is some *functional* (that is, a function of functions). Thus note that the template for laws that is assumed in the contemporary debate is *not* the old $\forall x(Fx \rightarrow Gx)$-type formulation that was so central to earlier discussions. The stated reason that Armstrong provides for this move away from the older representation is that

> The laws that have the best present claim to be fundamental are laws that link together certain classes of universals, in particular, certain determinate quantities falling under a common determinable, in some mathematical relation. They are functional laws. If we can give some plausible account of functional laws, then and only then do we have a theory of lawhood that can be taken really seriously (Armstrong (1993), p. 242).

Assuming such an account of fundamental laws, then, we can better formalize the canonical debate over their modal interpretation as follows. Suppose first of all that a fundamental law, say an actual fundamental law, is given by

$$a(x) = f(b(x), c(y), d(x, y))$$

for some specific properties and relations A to D. Anti-Humeans will then hold that since the fundamental properties are essentially dispositional, it follows that

$$\neg \diamond a(x) \neq f(b(x), c(y), d(x, y)),$$

and in particular that

$$\neg \diamond a(x) = f'(b(x), c(y), d(x, y))$$

for any $f' \neq f$. Thus in this context in which laws are conceived of in functional terms, it is not merely the *properties* to which a given property is related to that must be held fixed across possible worlds, but also the *way in which* it is so related, where that 'way' is expressed in terms of a functional connection between properties. By contrast, Humeans will hold that

$$\diamond a(x) \neq f(b(x), c(y), d(x, y)),$$

and in particular that

$$\diamond a(x) = f'(b(x), c(y), d(x, y)).$$

As noted above, if fundamental properties are categorical then it seems right to say that there should be no non-trivial constraints on the form of the laws that such properties feature in, and hence no non-trivial constraints on the choice of the functional f'.[9] But then another and more perspicuous way to characterize a categorical property is as one that is 'independent of its nomic role' (Mumford (2004), p. 150), where – as we are now in a position to state – that role is *defined* by (i) the functional form of the law and (ii) the identities of the properties to which the property is functionally related. That, I take it, may be regarded as the sought-for precisification of what is meant by 'categorical property', and as such of the Humean package as well.

That completes my outline of the canonical debate over the modal status of the laws of nature, as I understand it. What is assumed, first of all, is a fundamental modal distinction between properties which sorts them into 'categorical' and 'essentially dispositional', where I take the former sort of property to be most perspicuously defined as a moment ago. That modal distinction between properties is then used to ground a corresponding modal distinction between laws, defining the contingentists and necessitarians respectively. As is manifest from the quote from Armstrong above (and as would have been obvious anyway), it is explicit in this debate that the laws of nature of principal interest are the *fundamental* laws, and it is equally explicit that these laws are assumed to have a functional structure. But when the terms of the canonical debate are stated in that way, it becomes glaringly obvious that there is an urgent problem afoot in it. That problem, of course, is that this debate over laws played out in the metaphysics literature purports to describe fundamental laws and properties, and thus to capture the metaphysics of fundamental physics; *but fundamental physics properties do not obey functional laws*![10] The reason for this, of course, is that fundamental properties and the laws that relate them must be understood within the framework of quantum theory, and the laws of quantum systems simply cannot be shoe-horned into functional form.[11] But since categorical properties have been *defined* in terms of the relationship they bear to functional laws, what we

[9]By 'trivial' constraints on the functional form of laws that a categorical property A can participate in, I have in mind general conditions such as (i) there is no A-dependence on the right-hand side that cancels the occurence of A on the left (as in $a = f(b, c) + a$), or (ii) the form of the equation does not make it inapplicable to some of the determinates associated with the determinable (as in $a = 2$), etc.

[10]Or if we count charge as a fundamental property (which is controversial), at least not in its most 'fundamental guise' – Coulomb's law is after all just an approximation to the laws of quantum electrodynamics.

[11]To cite just one reason: the fact that in quantum mechanics some properties are quantized and others continuous entails that properties in general can no longer be representable by continuous functions, but rather should represented by matrices (some of which have continuous spectra and others discrete).

need to consider now is the question of whether *any* fundamental property can be classified as categorical when the latter are out of the picture.[12] Let me therefore now consider whether the fundamental properties may be regarded as categorical in the context of contemporary physics, and thus whether categorical properties may still be appealed to in order to ground a contingentist interpretation of laws. As above, I will continue to focus on the fundamental kind properties.[13]

3 Laws and Properties in Modern Physics: Problems for Humeanism

Given that functional laws are now out of the picture, the first item on the agenda is to clarify how laws are in fact represented in modern fundamental physics contexts. Since quantum field theory (QFT) is the most fundamental physical framework we have developed to date – certainly if we restrict our attention to those we can subject to empirical test – it is the structure of laws in QFT that we would ideally attend to directly. However, most of the critical points in what follows can be stated in the (far simpler) context of quantum particle mechanics, and as such I will elect to do so whenever we can get away with it. (While quantum quantum particle mechanics will serve us well in what follows, the final point I wish to make relates to QFT alone.)

To begin, then, let us focus on quantum particle mechanics. In this context, the nearest thing we have to a template for laws along the lines of the functional template of classical physics is the Schrödinger equation. Despite the presence of the definite article, 'the' Schrödinger equation is not so much *an* equation as a structure into which the various laws of quantum particles must slot, and laws of Schrödinger form relate the evolution of such a system to the action of the relevant Hamiltonian on the system states. They are therefore statements of the form

$$i\hbar\frac{\partial|\psi(n_i)\rangle}{\partial t} = H_\alpha|\psi(n_i)\rangle,$$

where H_α denotes some specific Hamiltonian and the n_i denote the properties that identify the kind, or kinds, of particle involved.[14] These Hamiltonians describe both how a single particle's states evolve in time through its Hilbert space, but also contain all the information about a particle's *interactions* with other systems. For example, the quantity

$$\langle(n, \pi^+)|H_S|(p, \pi^-)\rangle \tag{1}$$

[12] Since essentially dispositional properties are typically characterized in terms of their entailment of such laws, analogous problems will apply to them; but I forgo discussion of such properties here. The central point of this paper, after all, is to show that this whole debate needs to be rethought, not that some one side of it triumphs over the other.

[13] Since state-dependent properties in quantum mechanics are typically taken to be possessed only *conditionally upon measurement*, it is already clear that it will be difficult to maintain that *they* are categorical.

[14] Some state-dependent variables x_i should also be included in the characterization of the state, but as my focus is just on kind properties here I omit themin what follows.

yields the probability that two different particle kinds, here a negative pion and a proton, will interact through the strong interaction when smashed together in an accelerator to produce a positive pion and a neutron. These probabilities concerning which particles will be produced when others interact in this way essentially exhaust the empirical output of a theory of particle physics.

These facts about laws and probabilities in quantum mechanics are utterly elementary. But behind the elementary nature of these facts hide some important implications for modal metaphysics. The most expedient way to see this is to attend straight to the case in which there is some non-trivial *symmetry* at play in the dynamics expressed by H_α. While this is admittedly a special case in the space of all possible Hamiltonians, it is emphatically *not* a special case from the perspective of actual fundamental physics since all the known fundamental interactions are associated with some significant symmetry. In the context of quantum particle mechanics, to say that a law exhibits a symmetry is typically to say that there exists a set of observables U_i such that (i) the U_i are the generators of a unitary Lie group, and as such define a Lie algebra, and (ii) for all U_i, $[H_\alpha, U_i] = 0$, where H_α is the Hamiltonian corresponding to that law and $[H_\alpha, U_i] = H_\alpha U_i - U_i H_\alpha$. The presence of such a symmetry has important consequences for the solutions of the Schrodinger equation (here presented in time-independent form) – namely, that

$$H_\alpha \psi(n_i) = E\psi(n_i) \Rightarrow H_\alpha(\psi(n_i')) = E\psi(n_i'),$$

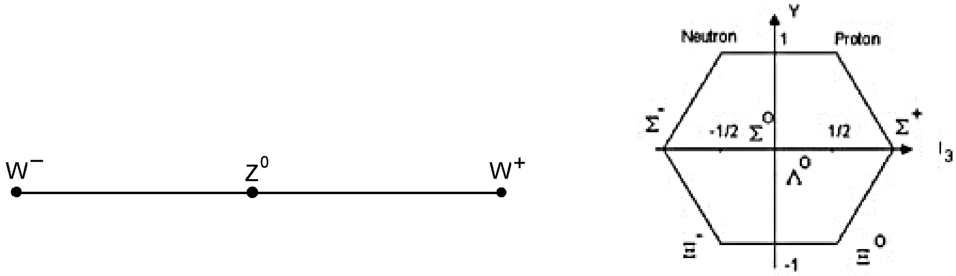
where E represents energy, the n_i again represent a set of determinate properties defining some kind, and the n_j a different set of determinates *but of the same determinables* as those that define the first. Thus where there are symmetries of the laws, there exist *families of particles* that obey those laws with the same energy (hence in relativistic contexts same mass), but that have different magnitudes of the same determinable properties. Such of families of particles are denoted as 'multiplets'. It is essentially because of this tight connection between symmetries and particle kinds that physicists are able to predict the existence of new particles long before they are seen in the lab (famous examples being the Z^0 and Ω^-).[15]

As already noted, the actual laws of physics themselves possess a great deal of symmetry: we have, for example, the SU(2)⊗U(1) symmetry of the electroweak interaction, and the SU(3) symmetry of the strong interaction. That means, of course, that the particles (and fields) that populate this world themselves fall into such multiplets. We have in Figure (1a), for example, the triplet of the weak bosons defined by their differing values of weak isospin, corresponding to the 3-membered multiplet of the SU(2) symmetry in the electroweak interaction. In Figure (1b), we find the neutron, the proton and other hadrons comprising the 8-membered multiplet of SU(3).[16]

[15]It should be noted that in the (more complicated) context of QFT, it remains that both the fields and the field quanta (particles) that act in accordance with a law will form multiplets of whatever symmetry that law is taken to have. As such, this observation concerning how the distribution of particle property magnitudes relates to the presence of dynamical symmetries transfers directly to the (more fundamental) quantum field-theoretic context.

[16]While hadrons are no longer regarded as fundamental particles, the gluons – which currently *are* so regarded – form a multiplet with an identical structure.

Figure 1: Some actual particle multiplets.



(a) SU(2) Triplet of Weak Bosons

(b) SU(3) Octets of Hadrons

3.1 Problems for Categoricalism

These diagrams represent elegant facts about the fundamental structure of the actual world. To see their principal relevance for topic at hand, however, it helps to recall that debates over the modal status of laws are often framed in terms of *duplicates*. We already know that Anti-Humeans hold that otherwordly duplicates of actual particles cannot act in accordance with different laws; as Bird puts it, for Anti-Humeans 'if the particles and fields are the same in two worlds then they instantiate the same [essentially dispositional properties] and thus give rise to identical laws' (Bird *op. cit.*, p. 84). Humeans of course deny this, holding that otherworldly duplicates of actual particles may accord with different laws (see e.g. Lewis (1986), p. 163). I have already pointed out that the extant literature is basically silent on the issue of just how much nomic variation is possible given categoricalism, but I have argued that the informal renderings of 'categorical' point to the idea that it should be possible for such properties to feature in laws with an *arbitarily* different structure. What, then, is the situation here? Can the behaviour of otherworldly duplicates of the actual particles, which as we know occur in *multiplets*, be described by laws with a structure arbitrarily different from those of the actual laws?

But the answer to this question is a clear and resounding *no*. A little more technically, what the above diagrams represent are *weight diagrams* of the algebras corresponding to the relevant symmetry.[17] Each weight in a diagram corresponds to a member of a particle multiplet, and the operators of the algebra may be defined so as to map between the various weights in the diagram. Each diagram may therefore be thought of as a sort of solution space for the algebra. Furthermore, a little more attention to the mathematical theory describing these entities – namely, the theory of semi-simple Lie algebras – allows one to deduce that each such weight diagram corresponds to *one and only one algebra*.[18] What that informs us of in turn is that,

[17]An algebra is one way to characterize a symmetry. It is not the most fine-grained way, granted, since the algebra is insensitive to the global properties that the associated group describes. Nonetheless, it remains that to pin down a symmetry up to the level of the associated algebra is still to determine a highly non-trivial constraint, and here – just as in most contexts in particle physics – I will be content to describe symmetries in algebraic terms.

[18]This is at least the case for the compact semi-simple algebras, which are those typically employed in particle

wherever it is in possibility space that duplicates of these actual kinds are instantiated, then if we understand the laws operative there along quantum-mechanical lines it follows that those laws *must possess the symmetry of the laws of the actual world*. But that represents a *hugely* informative and non-trivial constraint on the laws that any such set of duplicates can accord with. It may be shown, for example, that the probabilities for kind production given above in (1) may essentially be computed through consideration of symmetry alone; since as already noted the probabilities associated with outcomes of interactions essentially exhaust empirical output of particle physics theories, information about symmetry is *highly* non-trivial information from an empirical point of view.[19] As a result, knowledge of the symmetry associated with an interaction ranks high among the most significant information from a modern physicist's point of view, and indeed entire research programmes have flourished in the absence of any knowledge concerning the relevant laws that transcended their symmetry properties alone.[20]

But now we are in a position to see why the appeal to categorical properties is so very problematic in the fundamental physics context. We saw that in the canonical account – at least as I reconstructed it – the definitive feature of categorical properties was their *failure to place any non-trivial constraints* on the laws they feature in, including the structural *form* of those laws. What we see now, however, is that if we conceptualize fundamental laws in a way that approximates how *physics* in fact understands them, then in any possible world in which the actual kinds are reduplicated the symmetries of the actual laws must be reduplicated as well. But we know that this represents a *highly* non-trivial structural constraint on the laws that particle kinds can satisfy. How, then, can we say that the associated kind properties are categorical, if *part of what it is* to be categorical is to be free of such constraints?

The appropriate conclusion to draw at this point therefore seems to be this: we simply cannot understand the fundamental properties as categorical in character, at least not in anything like the sense in which such properties are canonically understood. And since it is primarily in the works of the canonical debate that these properties are articulated, it therefore isn't clear that there is any hope of retaining categoricalism *at all*.

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physics when dealing with internal symmetries. The basic idea behind this is as follows. The operators of any simple compact Lie algebra can be arranged into a maximal set of r commuting operators H_i, and a remaining set of ℓ operators E_α. Since the r commuting operators can be used to define those properties of the particles that can all be observed simultaneously with one another (and with the energy), it is the eigenvalues of these operators that are taken to define particle kinds. Each of these kinds is represented by a weight in the diagram. The remaining operators E_α are 'step' operators that map from one weight (particle) to another weight displaced from the first by a vector α. These α are also the 'roots' of the algebra, and the full set of these roots may be used to classify the algebra. It follows from the last point that two distinct algebras must differ in their roots, and thus differ in terms of how the weights in their associated weight diagrams are displaced from one another; it follows from that in turn that each weight diagram corresponds to one algebra only. And since semi-simple Lie algebras are just the sums of simple Lie algebras, each set particles associated with *these* algebras will likewise correspond to a unique such algebra.

[19] It should be noted that we must in general know more than the relevant internal symmetry group to predict the outcome of scattering experiments, as these outcomes are distributions in space (so that information regarding the external symmetries, the structure functions describing the material constitution of the colliding particles, etc., has to be invoked in addition).

[20] The Eightfold Way programme of Gell-Mann and Ne'eman is the classic example here (see Gell-Mann and Ne'eman (1964)).

3.2 Problems for Contingentism

The above considerations strongly suggest that the Humean must relinquish their commitment to categoricalism regarding the fundamental kind properties. But given that – in the canonical account at least – their modal interpretation of laws is *grounded* in the prior commitment to these properties, the same considerations surely threaten the contingentist approach to laws that defines the second aspect of their view. What I want to argue now is that these considerations do indeed put pressure not just upon the Humean interpretation of properties, but on their interpretation of laws as well.

The reason why the above considerations pose a threat to nomic contingentism should be immediately clear. The problems for categoricalism outlined above derive from the fact that the fundamental kind properties of this world, when conceived of post-classically, impose significant structural constraints on the laws that those kinds can satisfy. As such, the tighter these constraints get, the more diminished the scope for contingency. We saw above that these constraints amount to the fact that reduplicating the actual particles and fields reduplicates the symmetry associated with the actual laws, so what we must contemplate in order to go on is the extent to which pinning down a law's symmetry sufficies to pin down the law itself. Let us therefore attend to that now.

It was registered above that identifying the symmetry associated with a law furnishes us with highly non-trivial knowledge, from both a theoretical and an empirical point of view. However, it is not the case in general – either in classical, quantum particle, or quantum field theory – that a law is uniquely determined by the symmetry associated with it; knowing that a classical electromagnetic potential is spherically symmetric, for example, will not be enough to pin down the radial dependence of the potential uniquely (see e.g. Martin (2003) for discussion). However, as was mentioned above, the protagonists in this debate are not primarily concerned with natural laws *in general*: rather, they are primarily interested in giving a metaphysics of the truly *fundamental* laws and properties. The question we ought to focus on, then, is that of whether the *those* laws may be determined by symmetries alone.

As things turn out, and very interestingly, there is at least a case to be made that we should answer that question in the affirmative – for one can argue that the symmetry associated with a fundamental law *does* in fact suffice to determine it uniquely.[21] This is due to the fact that fundamental laws are required to have properties that less fundamental laws arguably need not, and the reason for this is roughly as follows. Again, the fundamental laws, if such there be, must be described in the most fundamental framework we have, and at the moment that is QFT . It has been understood since its earliest days that quantum field theories are plagued with divergences that must be removed through the complicated and arduous process of renormalization.[22] It came to light only later, however, that we can expect even properly renormalized theories to diverge at sufficiently high energy. Since relative to the background of QFT's assumptions a theory must be valid to arbitrarily high energy if it is to give a fundamental

[21] Modulo the assumption that we already have the kind ontology that the laws are supposed to describe in place, which in the context of particle reduplication scenarios will obviously be the case.

[22] Any introductory QFT textbook will outline this process for the uninitiated.

description of nature, of considerable interest to physicists is what properties a QFT must have in order to be valid in this limit.[23] In this connection, the physicist Frank Wilczek has argued that the only quantum field-theoretic laws that can be shown to exist in a computationally tractable way in this infinite-energy limit are those that are 'asymptotically free' – that is, those whose couplings disappear at infinity (Wilczek (1999)). Furthermore, Wilczek and others have shown that the only asymptotically free quantum field theories that can exist in four dimensions are the so-called *renormalizable local gauge theories* (see, e.g., Gross and Wilczek (1973); Politzer (1973)). But the pertinent point about such theories is that, for a given matter content, these are essentially *uniquely specified* once we have specified the relevant symmetry. Putting things a little more precisely, on the assumption that the fields concerned are specified, the laws are thereby also uniquely specified *but for the values of the constants* appearing in them. Determination of these constants is therefore a matter of matching them to experiment.

What we see, then, is that if we want to give a fundamental modal metaphysics that reflects current fundamental physics, there are compelling reasons to reject the claim that the actual particles and fields could behave very differently from the way that they actually do. This is because there are reasons to hold that the only variable factor in the laws describing their behaviour is the values of the numerical constants featuring in them. Now, it should be underlined that such differences in the values of constants can make for profound physical differences between *worlds*: think, for example, of how different this world would be if the electromagnetic interaction were a hundred times stronger at the distance of a femtometer, so that the strong force keeping the protons in atomic nuclei together was overtaken by the electromagnetic repulsion pushing them apart (see Quigg (2003)). Nevertheless,it remains that the degree of *nomic* variation permitted by the above-cited results is radically diminished in comparison to that countenanced in the canonical account. Indeed, if change in the values of constants is the extent of variation that the nomic contingentist can lay claim to, I submit that they are barely entitled to call themselves nomic contingentists at all.

4 Coda on Humeanism

The considerations outlined above regarding particles, symmetries and laws in modern physics demonstrate that each component of the Humean package has been either ruled out or, at the very least, backed into a tiny corner. It may therefore seem that we can only conclude that the Humean stance towards laws and properties is simply dead in the water. In particular, the fact that we are now encroaching upon necessitarianism about fundamental laws seems to be in flat contradiction with the Humean dictum that there are no 'necessities in nature', or at least no necessities that cannot be reduced to those of mathematics or logic. However, by way of rounding off this discussion I beg that we reconsider whether the necessities gestured at above are as unpalatable to Humeans as they may at first appear. I will argue that they are *not*, and as such that a Humean approach to laws is very much still in the offing.

[23]The requirement that QFTs must be regarded as valid in the infinite energy limit follows from the spacetime continuity required by Lorentz invariance in tandem with the complementarity of 4-momentum and spacetime in quantum mechanics.

At the root of the problems outlined above is the fact that, in quantum frameworks, the kind content of a given world determines the symmetry structure of the laws in that world.[24] The reason for that in turn was that, assuming that the laws concerned exhibit symmetries, the particles acting in accordance with those laws will fall automatically into *multiplets*, and the governing theory of Lie algebras dictates that each such multiplet corresponds to one and only one symmetry. But what I then ask that we consider is this: if this fact about the relation between Lie algebras and the associated multiplets is what lies at the root of the necessitation problem, then *what exactly is it* about this necessitation that is unacceptable to Humeans? Hume himself, after all, was perfectly happy to countenance the existence of necessities in the realm of 'relations of ideas', and so in in algebra, arithmetic and geometry; but is it not at bottom a *mathematical* fact that a set of particles, defined by a given set of determinate values, cannot participate in laws of quantum-theoretic form with arbitrary symmetry structure? It seems to me that it is; and as such, it seems to me that the mere fact that the laws describing a given set of particles may be unique and in that sense *necessary*, it is not a necessity that Hume himself need have felt particularly troubled by. And if the protagonists in the canonical debate had only realized that they were working with an unacceptably classical account of laws of nature for which the above considerations regarding kinds *cannot even get off the ground*, they too may have realized that Humeans can in fact countenance nomic necessity.

At this point I envisage an immediate objection to the above remarks concerning the necessity of the laws of nature and their compatability with Humeanism. This objection is that my argument suggesting that the laws that, for example, the hadrons can accord with are unique and in that sense necessary was made *relative to the assumption* that those laws are conceived of quantum-field theoretically. But since, one might hazard, there could be a world in which there are hadrons but in which *classical* physics holds sway, the necessitation arrived at is relative to that (substantive) assumption and is in that sense at best a 'contingent' necessity.[25] There are three things I would like to say by way of a response to this. Firstly, it is in fact entirely unclear that there could be a world that is both fundamentally classical and that could serve as an object of study by physics (see Mirman (1995), Chapter 1). Secondly, the canonical debate likewise makes substantive and contingent assumptions when it assumes that laws can be fit into the functional template. Therefore if the objection to my conclusion that the fundamental laws are necessary is that there could exist worlds in which the laws cannot even be expressed in terms of the relevant quantum-theoretic template, then one could make an exactly parallel objection to the Anti-Humeans in the canonical account – and indeed against anyone who would claim that any law at all is necessary. For how do *they* know what possible templates for laws are out there in possibility space? However, it seems to me that if we are to argue about whether the laws are necessary or not, *we need to agree at the outset* as to what sort of structural templates are going to count as laws *and then argue within that assumption*, by arguing about what variations within that template are possible. Finally, however, insofar as

[24] I was explicit above that I am making the assumption above that the worlds and laws in question exhibit some non-trivial symmetry. If this assumption is dropped my argument does not get off the ground, though as pointed out above making the assumption does not entail that the cases concerned are particularly 'special' from a physics point of view.

[25] Here I do not wish to connote the 'contingent necessity' associated with Armstong's analysis of laws.

the debate concerns what duplicates of a given set of entities are capable of in other possible worlds, it seems clear to me that we need to settle at the outset *what those entities are*. If we agree that those entities are quantum entities of some sort (whether particles or fields), then we *have no choice* but to use laws of the appropriate quantum form. As such, there really *is* no contingency in the framework we adopt to describe the behaviour of duplicates of the posited entities, and the above objection is simply moot.

5 Conclusion

I will be the first to admit that the argument I have laid out above is very sketchy in many places – far sketchier than it would have to be to establish its somewhat substantive conclusion. Nevertheless, I hope that I have, at least, managed to convey that the modal disputations we routinely engage in need to change, and change dramatically. I hope to have shown, first of all, that the 'canonical' debate played out in the metaphysics literature is explicitly wedded to an unacceptably classical view of the world. I hope furthermore to have shown that when we try to repeat the debate in the context of laws that bear more similarity to the fundamental laws of physics, we can no longer claim that the fundamental kind properties are 'free of nomic implications' and as such categorical in character; nor is there much scope to argue that the fundamental laws are contingent. However, I have argued that this necessaritarianism might, contrary to appearances, be entirely palatable to Humeans: it will be a Humeanism that is not built on the ediface of categorical properties, granted, but I think we can call it a Humeanism about laws nonetheless. Given that necessitarianism about laws was partly definive of the *Anti*-Humean position in the canonical debate, this circumstance vividly suggests to me that paying attention to the mathematics of real physics can change the landscape of modal metaphysics quite dramatically. What is crystal clear to me, in any case, is that we cannot continue to kid ourselves into thinking that by contemplating only the possibilities that might be sanctioned classically we can thereby arrive at a modal metaphysics that has any right to be called 'fundamental'.

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