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What is a Law of Nature? The Broken-Symmetry Story

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1. Introduction

In recent decades, cosmology and particle physics have joined their efforts in an attempt to understand the processes at work during the first moments of the big bang, when the universe as a whole was in a very hot and dense state. The most significant achievement of particle physics is the development of theories aimed at unifying the fundamental forces of nature: electromagnetic, weak, and strong. They manifest themselves rather differently at low energies because of the phenomenon of spontaneously broken symmetry. However, it is expected that, at very high energies, the symmetry among the forces is restored and that they can be described by a unified gauge theory.[1] Now the early universe may be the only locus of gauge unification because the conditions necessary for it could hardly be realized elsewhere. In this way, cosmology becomes a natural complement to particle physics. I argue that this remarkable symbiosis has important philosophical implications. In particular, the concept of spontaneous symmetry breaking, when it is viewed cosmologically, may cast new light on the nature of lawhood. In a sense, the universe may have not only a material but also a *nomic* history. If the nomic features of the physical contents of the universe—those having to do with the laws governing these contents—belong to its ontological furniture, one may reasonably ask if and how these features

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could survive the drastic changes the physical structure of the universe underwent in its historical career.

The view that nomic properties of matter belong to the ontological furniture of the world may be called *nomic realism.* This view was not very popular during the heyday of positivism, when the *regularity theory* of the laws of nature reigned supreme. Times, however, have changed. The last three decades have witnessed an extensive and rather devastating critique of the regularity account of laws and the emergence of various alternatives. A distinctive feature of all varieties of realism about laws is that they ascribe nomic necessity to nature. This can be done in a number of ways. Here I shall focus on two currently fashionable accounts: the Dretske-Tooley-Armstrong theory (hereafter DTA)[2] and the causal powers (or, as I prefer to call it, the nomic powers) theory.[3] There is an ongoing debate between (and around) these theories, and the issues raised in this debate are many and diverse. It is not my purpose here to address all such issues. But I take the current status of the dispute to be close to a standoff.[4] In an attempt to stir it up, I want to add a new question to its agenda: Do these theories of lawhood square smoothly with a contemporary physical perspective on laws? I show that the evidence coming from particle physics and cosmology raises new problems for the DTA account. The rival nomic ontology of causal powers, on the other hand, is perfectly consistent with the evidence in question and can, in fact, find additional support in it.

2. The Dretske-Tooley-Armstrong Theory

This theory emerged from the criticism of the regularity account of lawhood. The view that laws of nature are nothing but unrestricted "cosmic regularities" confronts a number of problems.[5] Here is a sample list. (1) Being a regularity is neither necessary nor sufficient for being a law. (2) Laws, but not mere regularities, support counterfactuals. (3) Law contexts, unlike mere regularity contexts, are intensional. (4) Laws, but not mere regularities, can be strongly supported by empirical evidence and have considerable explanatory power. (5) Laws, but not mere regularities, embrace an inner connection between lawfully related states of affairs.

What is needed to account for genuine explanatory potential, high susceptibility to empirical confirmation, objective causal relationship, and, in general, modal power inherent in laws is, in Dretske's apt expression, an "ontological ascent ... the shift from talking about individual objects and events, or collections of them" (1977, 263) to something else. The DTA theory is predicated on such a shift.[6] According to this theory, laws of nature are objective relations, not between objects, but between properties or universals they instantiate. What makes a given sample of water have density 1 g/cm^3 is not the fact that all samples of water have this density. Although this general fact trivially implies all its instances, it cannot explain or ground any of them. What does this job is a direct relation of "nomic necessitation" between properties *being water* and *having density 1 g/cm³*. The facts about the world expressed by laws are not general facts covered by universal regularities of the form '(x) $(Px \supset Qx)$' but atomic facts expressed by singular statements of the sort '$N(P, Q)$', where N is a postulated relation of nomic necessitation between universals *P-hood* and *Q-hood*.

Since DTA was specifically designed to overcome the difficulties of the regularity theory, it is easy to see how it succeeds in avoiding them.[7] To be sure, it has problems of its own.[8] In what follows, however, I abstract from those problems and focus on a question that has not yet received due attention: Can the DTA theory accommodate a perspective on laws offered by particle physics and cosmology? Before addressing this question, I want to outline briefly the rival theory of causal powers.

3. The Nomic Powers Theory

Put simply, this theory maintains that laws derive from the nomic properties of objects. Nomic properties come first and laws second. The former serve as the ontological ground for the latter. Consequently, the possession of nomic properties by particulars constitutes truth-makers for the statements of the laws describing the behavior of these particulars in various circumstances. This view presupposes a robust realism about natural kinds and a certain type of essentialism sometimes referred to in the literature as scientific essentialism.[9] In particular, members of natural kinds have their nomic properties essentially. The central claim of the theory is that nomic properties include dispositional, as well as categorical varieties. Dispositional properties and their species—propensities, capacities, tendencies, liabilities, trends—often go by the name of *causal powers* (although it is a matter of debate whether the former could simply be identified with the latter). The possession of such powers disposes their bearers to behave in specific ways or to exemplify other characteristic properties. The laws of nature are none other than the facts about dispositional nomic properties essentially possessed by natural kinds of objects. Given the actually existing natural kinds and their essential nomic features, the laws of nature follow necessarily. As a result, they exhibit a distinctive species of modality known as *natural necessity*.

The DTA theory and the causal powers theory agree that laws are something more (or something other) than regularities and that this distinction has to do with the nomic necessity possessed by laws and lacked by mere regularities. What they disagree about is the source, or ontological ground, of the nomic modality. Whereas DTA finds this source in second-order relations between universals, the causal powers theory points to the first-order nomic properties of objects themselves and claims that the essential possession of such properties by natural kinds constitutes the ground of laws in reality.

Viewed from a slightly different angle, the major issue dividing the two theories is whether one should drive a "metaphysical wedge" (in Ellis and Lierse's [1994, 30] apt expression) between *what* things are and *how* they behave. In the opinion of most DTA advocates, things are what they are in virtue of their *categorical* properties (having nothing to do with behavior), and they behave how they do partly in virtue of such properties and partly owing to particular laws of nature. Laws, on this view, are contingently imposed upon entities whose specific identity is quite independent of them. One and the same kind of thing, say, the electron, can submit to different laws in different worlds. The friends of causal powers argue that this view is fundamentally mistaken and resort for support to modern science. They concede that the separation of the nature of things from their behavior might be, to some extent, legitimate in the macroworld, where we deal with complex structures composed of more elementary constituents. Where such a structure, say common salt, is present, its dispositions, such as solubility, at least partly derive from the arrangement of elements, and such an arrangement appears to be a categorical property of the structure. When we get down to the most basic physical entities, however, we no longer find any structure to lean back on and must recognize irreducible dispositions as properties that ground both the behavior and the nature of fundamental objects. Their behavior is, in fact, indistinguishable from their nature. What makes something an electron, for example, is precisely a set of dispositions to behave and to interact with other such entities in specific ways. Nothing could be an electron without behaving like one. On this view, the fundamental laws of nature, rather than being imposed "from above," naturally arise from "bottom up." They emerge from irreducible dispositions of the basic individuals and confer on them precisely the kind of necessity the laws of nature are usually assumed to possess.[10]

The opponents of causal powers, however, remain unconvinced and insist that every disposition regarded by their rivals as irreducible—including those of the fundamental physical individuals—can (and must) be viewed as a joint product of a certain categorical basis and a contingent law of nature. I now want to show that this claim is problematic, by taking a closer look at what fundamental physics and cosmology have to say about laws. For this purpose, let me finally turn to the phenomenon of symmetry-breaking cosmological phase transitions.

4. Symmetry-Breaking Phase Transitions in the Early Universe

The first great success of unified gauge theories came in 1973 when the Weinberg-Salam-Glashow (WSG) theory unifying electromagnetic and weak interactions found experimental support in the discovery of neutral weak currents. The subsequent detection in 1983 of massive intermediate bosons $W^{\pm}$ and Z^0 predicted by WSG brought a real triumph and instigated the search for more comprehensive unified theories.

Electromagnetic and weak forces manifest themselves differently in a low-energy world because the former are mediated by massless photons (accounting for the long-range character of the electromagnetic force) and the latter by massive particles $W^{\pm}$ and Z^0 (thus making the range of the weak interaction extremely short). A theory aimed at unifying forces that appear so different must explain the origin of this asymmetry. WSG does so by starting with the four massless particles (complete symmetry) and then postulating the coupling of their associated fields with an additional field (called Higgs field) in such a way that $W^{\pm}$ and Z^0 acquire nonzero masses whereas the photon remains massless. This effect, known as spontaneous symmetry breaking, is due to a peculiar property of the Higgs field. At high temperatures, its vacuum state is completely symmetric resulting in zero masses of all four boson fields interacting with it. As temperature decreases, however, a *phase transition* occurs in the Higgs vacuum producing a less symmetric state, which accounts for nonzero masses of $W^{\pm}$ and Z^0 bosons but leaves the photon massless.

Such a temperature decrease is precisely what happens in the course of cosmological evolution. Consequently, as the universe cooled down from its initial hot state it may have undergone, quite early in its career, one or more mass-generating symmetry-breaking phase transitions. To be sure, nobody has ever observed such a phase transition in the vacuum of the Higgs field. One can only hypothesize that this event has occurred in the distant past of the universe. It turns out, however, that a certain type of cosmological phase transition has multiple causal consequences, being responsible not only for mass generation but for a short period of very rapid expansion (called inflation) of the early universe, which is required to account for certain manifest features of the observable universe.[11] This gives one strong enough reason to believe that an event of this sort did occur in the history of the universe.

We live in a low-energy cosmic epoch (with the average temperature of approximately 3° K). Because of this, the photon is massless whereas the masses of $W^{\pm}$ and Z^0 bosons are not zero (specifically, $M_W \approx 80$ GeV, $M_Z \approx 90$ GeV). But if one could warm up the material contents of the world to approximately

10^2 GeV (10^{15} K), the symmetry presently broken would be restored, and the masses of all bosons would vanish. The actual history of the universe includes the inverse process of separation of the electromagnetic and weak forces at about 10^{-10} sec after the big bang. This suggests a close parallel between the material and the nomic histories of the universe.

How could a theory such as DTA deal with it?

5. DTA and Cosmic Epochs

Consider a universal statement that all Z bosons have mass 90 GeV:

(1) $(x)(Zx \supset M_z x)$,

where '*Z*' stands for the property *being a Z boson* and 'M_z' for *having mass* M_Z ($M_Z \approx 90$ GeV). As it stands, (1) is false. According to the theory of cosmological phase transitions, Z bosons have mass M_Z only in our low-energy epoch. In the very early universe, when the temperature was higher than $T_c \approx 10^{15}$ K (the characteristic temperature of the electroweak phase transition), the presently broken symmetry between electromagnetic and weak interactions was still in place and all intermediate bosons had vanishing masses.

One could perhaps give the following description of the situation. Statement (1), though false, can be made true by restricting its scope:

(2) $(x)(Zx \supset M_z x), t > t_c$,

where $t_c \approx 10^{-10}$ s is the moment of the electroweak phase transition in the cosmological timescale. As one goes back in time and reaches t_c, (2) ceases to hold but another restricted regularity takes over:

(3) $(x)(Zx \supset Ox), t < t_c$,

where '*O*' denotes *having zero mass*.

The following question can now be raised for the DTA theory: Can *Z-bosonhood* bear any relation of nomic necessitation *N* to some determinate *masshood*, in light of (2) and (3)? Hardly so. If *Z-hood* bears *N* to M_z*-hood* then it cannot bear the same sort of relation to *O-hood*. Indeed, suppose *Z-hood* bore such relations to both M_z*-hood* and *O-hood*. According to DTA, this would mean that *any* Z boson must have M_Z by virtue of the relation of nomic necessitation *N* between *Z-bosonhood* and M_Z*-masshood*, and *any* Z boson must have zero mass by virtue of the same sort of nomic relation between *Z-bosonhood* and *zero-masshood*. This is clearly impossible. One and the same thing cannot have both mass M_Z and mass zero.

But why not say that *zero-masshood* is nomically necessitated by *Z-bosonhood before* t_c because of the relation N obtaining between them *at that time*, whereas after t_c, *zero-masshood* is no longer necessitated by *Z-bosonhood*, giving its way to M_Z*-masshood*, because of the same sort of nomic relation *now* obtaining between the latter? This suggests a picture of universals changing their relations to one another with time. But this picture is metaphysically implausible. Universals are not the kind of entities that can change their properties with time. Here, an important distinction must be kept in view. Universals, in DTA, can have different properties (and, in particular, bear different relations to one another) in different *worlds*. This is what makes the laws of nature in the relevant sense contingent. But universals cannot have different properties at different times *within* a world.[12]

Consequently, DTA must recognize no law of nature relating *Z-bosonhood* with any determinate *masshood*. This conclusion, however, is problematic. The relation between *being a Z boson* and *having mass 90 GeV* appears to have the real force of lawhood in *our* cosmological epoch (just as the relation between *being a Z boson* and *having mass zero* appears to have had the same nomic force before the phase transition). At the very minimum, it supports the relevant counterfactuals (if something that is not, in fact, a Z boson had been one at $t > t_c$, it would have had mass 90 GeV); has the requisite modal power (all Z bosons after t_c have mass 90 GeV, not just as a matter of fact, but of necessity); and is confirmed by its instances because it is able to explain them (what does the explaining is the *inner* connection that is certainly present between *being a Z boson and existing after* t_c and *having mass 90 GeV*). How would an advocate of DTA account for these manifest lawful features of what cannot, on their interpretation, be a law?

One tempting proposal may be to take a cue from Goodman and introduce the property *having mass zero*/M_Z, expressed by the predicate '$M_{o/z}$', as follows: something is a $M_{o/z}$ just in case it has mass zero and the time is before t_c or has mass M_Z and the time is after t_c. Given this, restricted universal statements (2) and (3) could be combined in a single unrestricted statement of a genuine cosmic regularity:

(4) $(x)\,(Zx \supset M_{o/z}\,x)$,

and a genuine law of nature presumably standing behind this regularity could be construed, in accordance with DTA, as the relation of nomic necessitation N^* between properties *being a Z boson* and *having mass zero*/M_Z:

(5) $N^*(Z, M_{o/z})$.

Goodmanian properties, however, are prima facie suspect. They become even more so when one attempts to construe them realistically, as multiply exemplified genuine entities (and that is precisely what the DTA theory presupposes). Nomic properties, when they are so construed, are expected to be causally efficient, that is, capable of necessitating, via the relation N^*, the having of other properties or of being necessitated by them. But it is hard to see how *having mass zero/M_Z* could be a genuine and causally efficient nomic property. It looks more like a gerrymandered combination of two different properties. Indeed, having mass zero/M_Z does not involve anything over and above having mass M_Z after t_c and having zero mass before t_c. A Z boson that occurs after t_c has M_Z by virtue of being M_z, and this sufficiently accounts for its relevant causal features at that time. Simply appending *being-O-at-$t < t_c$* to *being M_z* does not add anything to this account. The nomic efficiency of *being M_z* at $t > t_c$ is no more explained by conjoining it with *being-O-at-$t < t_c$* than P is explained by conjoining it with Q to form $P\&Q$. Furthermore, the way in which *being M_z* and *being O* are conjoined in *being $M_{o/z}$* makes cosmological time a constituent of the alleged universal *$M_{O/Z}$-masshood* and that, again, is metaphysically problematic. By their very nature, universals cannot incorporate time any more than they can change their properties with time. Thus invoking Goodmanian properties does not allow one to avoid the initial difficulty.[13]

The DTA theorist must conclude that the relation between *being a Z boson* and *having mass M_Z* cannot be a matter of law in the post-transition cosmic epoch, any more than the relation between *being a Z boson* and *having mass zero* can be in the pre-transition epoch. This, as we have seen, does not sound right. It is nomically necessary for a Z boson to have mass M_Z today, as it was nomically necessary for it to have mass zero before t_c. The requisite sort of necessity cannot be grounded in a relation between such universals as *being a Z boson* and *having mass M_Z* or *having mass zero*.

6. Relations Between Universals Versus Nomic Powers

But could it not be grounded in a relation between more complex universals, such as *being a Z boson at temperature T* and *having mass M_Z* (*mass zero*)? Or else, could one not take a route suggested by Tooley's version of DTA (1977, 1987) and, instead of increasing the complexity of the universals involved, allow more complex, *n*-ary relations among simple universals, such as *being a Z boson*, *being at temperature T*, and *having mass M_Z /mass zero*? Consider a similar situation. It is nomically necessary for H_2O to have density 1 g/cm^3 at temperatures above 0° C and density 0.9 g/cm^3 below 0° C. The relevant sort of necessity cannot be grounded in a relation between *being*

H_2O and *having density* ρ (where ρ is some determinate density value). But the friend of DTA might decide to ground it, instead, in a relation between *being H_2O at T* and *having density* ρ, or, alternatively, in a triadic relation among *being H_2O, being at T*, and *having density* ρ. To make the analogy even closer, suppose everything in the universe had the same temperature and this temperature were decreasing with cosmological time. One would then register a "nomic evolution" in the lawful properties and behavior of H_2O as the universal temperature dropped below 0° C. At that moment, a phase transition would occur that would have changed the nature of H_2O from water to ice. But there would be laws relating universals *being H_2O at T* and *having density* ρ (alternatively, laws relating universals *being H_2O, being at T*, and *having density* ρ) before, as well as after, the phase transition. Is, then, the case of the symmetry-breaking cosmological phase transition in the Higgs vacuum any different? If not, the DTA theorist could maintain that there are laws relating *being a Z boson at T* and *having mass M* (or else, laws relating *being a Z boson, being at T*, and *having mass M*) both before and after the electroweak phase transition in the early universe.

This response, however, confronts further difficulties. First of all, the DTA theorists typically reject the notion that, to every general predicate, there corresponds a genuine universal. The sort of realism most congenial to DTA is a sparse and a posteriori realism about universals. What universals there are should be decided "on the basis of total science" (Armstrong 1983, 83), not on the basis of semantics. "It is to natural science ... that we should look for knowledge, or perhaps just more or less rational belief, of what universals there are" (Armstrong 1997, 25). Secondly, the DTA theorists draw (again, absolutely rightly) a distinction between basic and derivative laws (e.g., Armstrong 1983, 145 ff). Only the former are, strictly speaking, genuine laws relating genuine universals. Derivative laws may or may not themselves involve universals related in a certain way, but in any event, such relations are not the ultimate ground for derivative laws. The latter derive their nomic power from the underlying irreducible relations between more basic universals. On this approach, is *being H_2O at T* a genuine universal? Doubtful. But even if it is, the real source of the nomic necessity forcing H_2O to have a particular density at a given temperature is to be found, not in a multitude of facts about H_2O at various temperatures, but in a single nomic fact about H_2O, namely, its molecular structure. It is because of this structure that H_2O has ρ_1 at T_1, ρ_2 at T_2, etc. It would be against the spirit of DTA (and, in fact, against both science and common sense) to introduce, besides the laws of molecular and atomic interactions, an infinity of further laws relating such properties as *being H_2O at T_k* and *having density* ρ_k (or, alternatively, relating such properties as *being H_2O, being at T_k*, and *having density* ρ_k in the corresponding triadic relations).

Nonetheless, the case of H_2O does not pose any serious problems for the DTA theorist. She could say that the relevant genuine laws—those concerning the molecular and atomic nature of H_2O—are relations between genuine universals after all, even though it is hard to say precisely what these are. But no similar move is allowed in the cosmological case. To see why, note, first, that, just like H_2O, the Z boson has different nomic properties (such as mass) at different temperatures because of certain fundamental and rather sparse nomic facts about the Z and the Higgs fields, not because of the multitude of derivative facts about the Z particle at various temperatures. If there are such universals (doubtful though it is) as *being a Z boson at T* they may bear certain relations to the having of particular masses. But such relations (just like the triadic relations among *being a Z boson, being at T*, and *having mass M*, in the Tooley version of DTA) would piggyback on the more basic nomic properties of the Z and the Higgs particles or fields and, hence, are not the real truth-makers of the corresponding laws. Unlike the case of H_2O, however, the underlying nomic properties of the Z and the Higgs bosons are not their structural properties. Being basic entities, these particles lack structure. Their relevant nomic properties are dispositions to interact with each other in certain ways. The Z boson, for example, can be said to have the disposition to couple minimally (in the way prescribed by the Lagrangian of the WSG electroweak theory) with the Higgs field and become massive or remain massless, depending on the vacuum state of the latter. Such irreducible nomic powers, and not relations among universals, constitute the ontological ground of the fundamental laws and of all their nomically necessary consequences. Thus it is nomically necessary that all Z bosons in the post-transition cosmic epoch have mass 90 GeV. What makes it so is a certain fact about the nomic powers of at least two basic quantum fields.

Could not the DTA advocate still insist that the fact in question obtains in virtue of some relation of necessitation between genuine universals? Could not one of them be identified with the Z boson's *relational* property of *having a certain relation R* to the Higgs field? If so, could there not be a law construed, in accordance with DTA (cf. Armstrong 1983, 154–5), as a relation between *having R to the Higgs field* and *having mass M_Z* obtaining in the post-transition epoch and a corresponding law holding before the phase transition? Much depends here on what sort of relation the postulated *R* is. Clearly, the entire content of the physical law in question is now packed into *R* itself and not into an alleged relation of nomic necessitation between *having R to the Higgs field* and *having mass M_Z* (or *zero*). *R*, therefore, is required to bring this content out. If 'having *R* to the Higgs field' means *being in the Higgs field at temperature T* (or something like that), then casting the corresponding physical law in terms of *R* does not give a clue to the real source of nomic necessity. Something can be "in the Higgs field at T" and not acquire mass. The case in point is the photon, a close partner of the Z in the WSG theory. Whether or not something "in the Higgs field at T" does in fact acquire mass depends on whether it has the relevant causal power, namely, the power to interact in an appropriate way with the Higgs field. So the necessity attendant to the Z boson's actually acquiring nonzero mass (after the phase transition) proceeds from the specific *interaction* between the Z-boson field and the Higgs field, not from the mere "presence" of a Z boson in the latter. Assuming, on the other hand, the postulated relation *R* to be the required relevant relation of interaction effectively introduces basic nomic powers into the picture, for the specification of *R* will now have to include the reference to the dispositions of the basic entities to interact with each other in a particular way. But introducing causal powers would make the necessitation relation between the corresponding universals redundant. This relation would simply piggyback on causal powers and could not be regarded as the ultimate ground of the relevant law.

7. What Does It Take to Be a Z Boson?

To do justice to particle physics and cosmology, the DTA theory is thus forced to concede too much to its rival: it has to acknowledge the existence of irreducible nomic powers of fundamental particles, namely, their capacities to interact with each other in ways prescribed by the Lagrangian of a corresponding physical theory. Such capacities, and not any alleged categorical properties, make the members of fundamental physical kinds what they are and distinguish them from members of other such kinds.

The ontology of nomic powers is compatible with realism about universals (there can be both powers and universals) and may even require it. But it sits poorly with the DTA account of lawhood. If the laws of nature derive from the ascription of causal powers (dispositions, propensities, tendencies, capacities) to particulars, the postulation of a special relation of necessitation between universals does no real work in explaining lawhood and hence cannot constitute a real ground of laws.

I did not attempt here a systematic defense of the powers ontology.[14] My purpose was to argue that, quite apart from other considerations, the ontology of nomic powers naturally emerges from the present-day synthesis of cosmology and high-energy physics. Even the most basic properties of fundamental objects (such as the masses of elementary particles) prove to be immersed in the flow of evolution.[15] They can no longer be regarded as intrinsic features of their bearers, as they result from the interaction of basic entities with each other, as well as from the vicissitudes of evolutionary history. Powers of fundamental objects to interact with one another in specific ways may constitute the only sort of property capable of surviving the global change of the universal scene. If this is so, the fundamental laws of nature (realistically construed) are naturally grounded in the irreducible facts about such powers.

The DTA theorist, to be sure, would want to do just the opposite: to start with some categorical properties of the fundamental entities, to postulate laws construed as second-order relations among such properties, and then to use both laws and categorical properties to derive causal powers. But the cost associated with such an approach has now been raised. In the end, the problem boils down to the question of what it takes to be a certain type of elementary particle, such as the Z. If symmetry breaking is a mechanism responsible for generating the familiar attributes of microobjects (such as rest mass), such attributes are secondary. They arise out of more fundamental "interactional" properties constitutive of basic natural kinds. What makes something a Z boson is precisely its dispositions to interact in certain ways with the Higgs field and other relevant fermionic and bosonic fields.

To override these considerations, the DTA theorist would be hard pressed to identify a plausible categorical basis for such a disposition. But it is difficult to see what could constitute such a basis uniquely picking out a particular fundamental natural kind, such as the Z. Things of this sort simply do not have identity independent of their powers. Among the familiar properties of the Z we find its charge, spin, and mass. Even if charge and spin could somehow be construed as categorical properties, their particular values do *not* pick out the Z *uniquely*: this particle shares zero charge and (the absolute value of) spin one with the photon. Mass would indeed pick out the Z—*if* mass *were* an intrinsic property of the heavy Z, thus distinguishing it from the zero-mass photon. But we now know that it is not. The mass of the Z is secondary. "Prior" to the interaction with the Higgs field, the Z *lacks* mass[16] and, hence, finds itself completely on a par with the photon. The distinction between them emerges only *after* the capacity of the Z to interact in a mass-generating way (and in the post-transition cosmological epoch)—a capacity lacked by the photon—is taken into account.[17] To represent this interaction as grounded in the categorical properties of the relevant fields and a contingent nomic relation between them, the friend of DTA would have to find a way of getting at the specific identities of these fields without including their interaction capacities as part of such identities. But how could one succeed in this, if what makes some vector field the Z field is, not merely partly but *exclusively*, the set of its specific nomic powers? Take them away—and nothing is left of the Z field.

As far as I can see, the only strategy left open to the opponents of nomic powers is to dig in their heels at this point and to insist that, despite all appearances, there is some categorical core—call it *Z-bosonity*—underlying various nomic powers of the fundamental entities, such as the Z. Since physics does not tell us anything about such a core, it appears to be incumbent on the categoricalist to provide an account of it. Such an account may or may not be possible, but the task of articulating it lies with the categoricalist camp.[18]

Notes

[1] A genuine unification of *all* fundamental forces is, at present, only a theoretician's dream. Furthermore, it is far from clear that the unification of which particle physicists speak means a genuine ontological reduction. For useful analyses, see Morrison 1995 and Maudlin 1996. But certain well-confirmed results of the unification program have, as I show below, important ontological consequences.

[2] Due to Dretske (1977), Tooley (1977, 1987), and Armstrong (1978, 1983, 1997).

[3] Recently advocated by Bigelow et al. (1992), Ellis and Lierse (1994), and Ellis (2001). See also Harré and Madden 1975; Shoemaker 1980, 1998; Swoyer 1982; and Fales 1990. Cartwright (1983, 1989) is a friend of causal powers but not a friend of the fundamental laws of nature. So it would probably be wrong to put her, without qualification, in the *nomic* powers theory camp.

[4] See, in this connection, Armstrong et al. 1996, Riggs 1996, Mumford 1998, and Sankey 1999.

[5] A thorough exposition of such problems can be found in Dretske 1977 and, especially, in Armstrong 1983.

[6] In my brief exposition I abstract from the differences between various versions of DTA. Some of these differences are important in their own right. Unlike Tooley, for example, Armstrong rejects uninstantiated universals and, hence, uninstantiated laws. This gives his theory a distinctively Aristotelian flavor, as opposed to the explicit Platonism of Tooley's conception. Nothing in my arguments, however, turns on such details. The same is true of my brief account of the nomic powers view in the next section. This account glosses over many distinctions among different versions of the view in question, distinctions important in their own right but inessential to the points I make in this paper.

[7] An interested reader is referred to the above-mentioned works of Armstrong, Tooley, and Dretske.

[8] See, in this regard, van Fraassen 1989, ch. 5.

[9] For a definitive statement, elaboration, and defense of scientific essentialism, see Ellis 2001.

[10] See Bigelow et al. 1992.

[11] See, for example, Linde 1990.

[12] The intuition behind this is that nothing is supposed to undergo change in the Platonic heaven. Moments and intervals of time are

particulars, whereas universals, considered *qua* universals (and this includes their relations to other universals), must be free of any particularity. This intuition may not be sacrosanct, but abandoning it would make the metaphysics of universals underlying DTA rather unnatural, which, in turn, would significantly raise the cost of the theory.

[13] In addition to these considerations, there is a sense in which embracing gruesome properties and predicates may be generally unacceptable to DTA theorists who have urged that their account solves the new riddle of induction, on the grounds that gruesome predicates do not correspond to genuine properties. Allowing such predicates back would undermine this point. I owe this observation to an anonymous referee.

[14] For a recent discussion of the advantages and problems of the nomic powers theory and responses to several objections, see Armstrong 1997, chs. 5 and 16; various contributions to Sankey 1999; and Ellis 2001.

[15] If supersymmetry is a viable theory, this may also be true of such properties as *being a fermion* and *being a boson*.

[16] Or, perhaps, has zero mass. See Balashov 1999.

[17] This picture is, of course, oversimplified. According to the WSG theory, what really interacts with the Higgs field is not the photon and the Z-boson fields themselves but their "ancestors" whose linear combinations emerge, after a suitable "mixing," as the photon and the Z. (For a generally accessible account, see Maudlin 1996; for a somewhat more technical, but still very readable exposition, see Moriyasu 1983, ch. 8.) But this does not change anything of principle. The "ancestral" fields are still distinguished by their capacity to interact, in different ways, with the Higgs field, as reflected in the corresponding terms in the Lagrangian of the WSG theory.

[18] I am indebted to David Armstrong, James T. Cushing, Michael Loux, and an anonymous referee for helpful comments on earlier drafts. An ancestor of this paper was presented at the Eastern Division meetings of the American Philosophical Association (Philadelphia, December 1997). Special thanks are due to my commentator Carl Hoefer.

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