49   Fundamentality

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49.1 Introduction

The idea that there is some fundamental "level" or "ground" where our description of the world bottoms out has acquired the status of 'the received view' in metaphysics (a classic statement of this view can be found in Oppenheim and Putnam (1958); for a more recent critical defense, see Cameron, 2008). Typically this view is cashed out in terms of some set of 'basic building blocks' populating this level, which sits at the bottom of a hierarchy ordered according to some set of compositional principles. These fundamental building blocks are thus taken to have some form of "ultimate" ontological priority with regard to everything else in the hierarchy. In this chapter I shall consider two kinds of threats to this view: the first comes from arguments against the idea of such a level in general, whereas the second concerns the nature of these occupants. As we'll see, both these threats become entwined in the context of modern physics but I'll conclude with a suggestion as to how this "received view" may be maintained in this context.

My discussion can be situated in the context of a vigorous debate over the relationship between metaphysics and science. In particular, it has been claimed that much of current metaphysics is too far removed from modern science and dependent on intuitions and "aprioristic" reasoning (see Ladyman et al., 2007, Ch. 1). Instead, it is argued, metaphysics should be more 'naturalistic' in the sense of drawing upon and responding to the results of science. In response, some metaphysicians have insisted that metaphysics has to do with what is *possible*, rather than what is actual and so should not be required to accommodate the impact of recent scientific developments (Lowe, 1998). In what follows the broad framework that I shall adopt with regard to this relationship will be that set out in (French and McKenzie, 2012, 2015): on the one hand, if metaphysics is to be understood as saying something about reality, then the implications of modern science and, in particular, physics need to be properly appreciated and this in turn will impact on certain "paradigmatic" metaphysical accounts, such as the received view, above; on the other, one does not have to accept that non-naturalistic metaphysics should be dismissed or even "discontinued" as some have pressed (Ladyman et al., op. cit.), since it can still serve as a kind of "toolbox" from which various devices and

maneuvers can be extracted and put to use. In what follows I hope to illustrate both aspects of this framework.

49.2 The Idea of the Fundamental

Let us begin by considering the alternative to the 'received view': there is no such 'bottoming out'. There are two obvious ways to conceive of such an alternative: first, that any ontological priority is not ultimate; that is, nothing is fundamental. If one likes the picture of reality as organized into hierarchical levels (a contested picture for sure) one can understand this in terms of the hierarchy either not bottoming out or not topping out, or both – it just "keeps on going" "down" or "up" or in both directions, as it were. The first option generates what is typically called a "gunky" ontology; the second a "junky" one, while the third yields a "hunky" ontology (see Tahko 2018, pp. 5–6). The "gunky" view seems to have received more attention, perhaps because, in the context of the history of physics, it seems to be a "live" possibility (thus to jump ahead to the discussion of the second issue above, Saunders has suggested that reality could be structural "all the way down" (Saunders, 2003)). It is obviously more difficult to similarly naturalize the "junky" and "hunky" ontologies as "the Universe" seems a natural "topping out" point. One could perhaps advert to recent considerations of the "multiverse" in cosmology but leaving aside the issue of whether this truly meshes with a junky metaphysics, the suggestion currently remains extremely speculative.

The second way of conceiving reality as not involving anything fundamental is to deny the idea of ontological priority itself. Doing so across the sciences is obviously problematic: although most commentators acknowledge that establishing the reduction of biological theories and models, say, to chemical or physical ones is notoriously difficult, most will also agree that there is an ontological reduction, from proteins to molecules and thence to atoms and elementary particles. And this reduction will obviously follow the "chain" of priority. There is more to be said, of course, but here I will simply assume such a reduction in what follows.[1]

What sorts of arguments, then, might be deployed in defense of the denial of ontological priority? Schaffer, famously, has offered an inductive one, from the history of science:

> The history of science is a history of seeking ever-deeper structure. We have gone from "the elements" to "the atoms" to the subatomic electrons, protons and neutrons, to the zoo of "elementary particles," to thinking that the hadrons are built out of quarks and

now we are promised that these entities are really strings, while some hypothesize that the quarks are built out of preons (in order to explain why quarks come in families). Should one not expect the future to be like the past? (Schaffer, 2003, p. 503)

Stated as such, the argument is really sweeping, taking us from the Greeks, through Dalton, to Thomson, Chadwick, Gell-Mann, and beyond. Perhaps it is too sweeping for many tastes, covering too many different kinds of putative fundamental entity, conceptualized in too many different kinds of ways, from "the elements" to strings. In that case, just consider the history of the last 50 years or so and the way in which order was brought to the so-called "particle zoo" of the 1960s via the quark model. Originally this posited just three kinds of quarks – "up," "down" and "strange" – which, together with their corresponding anti-particles, compose the multitude of hadrons. Within a year a fourth was introduced, with the flavor "charm" and with the subsequent addition of "top" and "bottom" quarks we now have six. Each comes in three "colors" and in addition there are six kinds of leptons, three of which – the electron, the muon, and tau – are charged and three – the corresponding neutrinos – are not. Thus we have 24 elementary fermions – 18 quarks and 6 leptons. Plus their anti-particles. Plus the various bosons – the photon, the W+, W− and the Z, the gluons and, of course, the Higgs boson. Even if we dismiss the bosons as "mere" force carriers, and ignore color, we're left with six quarks and six leptons, fueling speculation that there is a further "level," occupied by "preons," perhaps, as Schaffer mentions, although there is little evidence for them so far (Pati and Salam, 1974).

Whether or not such evidence eventually emerges from the Large Hadron Collider, say, drawing on the history of science like this is notoriously problematic. Even if we focus only on the recent history of physics, we might wonder whether we *should* expect the future to be like the past, at least when it comes to this search for "ever-deeper structure." To insist that we should strike some as resting on an implicit and speculative assumption that goes beyond the kind of naturalistic metaphysics that focuses on our current best theories (McKenzie, 2011, p. 246). However, even though one may be unconvinced by Schaffer's argument as originally stated, with its broad historical sweep, it may retain some force in the form of the more narrowly focused alternative. Of course one might still object that as presented even the historically narrower version of the argument rests on an assumption that is perhaps hard to justify as it stands, namely that of a principle of the ontological economy that drives a reduction in the number of kinds of entities that should be regarded as fundamental. What justifies such a principle? One could insist that reality itself is economical with regard to the number of kinds of things that there are but for this to be naturalistically acceptable, it would have to be grounded in the physics itself, rather than simply assumed, or at least so it could be argued. Furthermore,

given this, why should we assume that such a principle will always be "in play," as it were, and thus applied to future physical theories?

Given these concerns, are there non-historical arguments that can be mounted against the "received view?" McKenzie offers what she calls "internal" arguments against this view, formulated within the perspective of particular theories (ibid.). Thus, for example, consider the (in)famous "bootstrap model" of the strong interactions (see Chew, 1962) in which the idea that some particles are "elementary" and hence fundamental, is dropped, yielding what was referred to as a "nuclear democracy." Of course, as McKenzie explicitly acknowledges, this model was subsequently abandoned but nevertheless as she emphasizes it offers a useful case study, not least for demonstrating that fundamentality questions may be empirical in character. Nevertheless, the threat to the "received view" is blunted somewhat: the bootstrap model yielded reiterations of the same *kinds* of particles and hence still endorsed a form of fundamentality, albeit in terms of *properties*, rather than particles *per se* (ibid., p. 254).

In a similar vein, Callender has urged Schaffer to look, not to the history of science, but to even more recent physics for support, in particular to 'effective quantum field theory' (Callender 2001; see Wallace, (this volume), Section 5, for more details on effective field theories). I'll return to the impact of quantum field theory (QFT) on fundamentality claims in the next section but here we have a QFT applicable at a particular energy level approximating arbitrarily well another QFT at a higher energy level. The former is said to be an "effective" field theory for the latter, which is more fundamental. With an infinite number of energy levels, or scales, we obviously get an infinite "tower" of such theories, a prospect that Cao and Schweber (1993) argue may actually be true and which, again, obviously meshes with a "gunky" metaphysics, insofar as we begin, as it were, with the zero-energy levels and proceed to higher and higher levels without "bottoming out" (for criticisms see Huggett and Weingard, 1995; see also McKenzie 2017a for further nuanced considerations). Schaffer himself acknowledges (op. cit., pp. 504–505) that this example offers a "cautionary tale" to the fundamentalist and concludes that the empirical evidence is neutral between the two conceptions of the "hierarchy of nature": fundamentality and infinite descent (ibid., p. 505). Hence, he suggests, we should remain agnostic.

A further challenge to the "received view" might be drawn from the consideration of certain kinds of "dualities" found in QFT and string theory (see Dawid (this volume) for more details of string theory's dualities). Thus McKenzie considers the Montonen-Olive or electric-magnetic, duality according to which, in particular theoretical contexts, equivalent field formulations can be constructed in which electric and magnetic "charges" exchange roles (for

details see Polchinski, 2017. According to one such formulation, electrons are elementary particles and magnetic monopoles are "emergent" composite topological solitons; according to the other, the latter are elementary and the former are the composite solitons. These equivalent formulations can be seen as "complementary perspectives" on the same theory and hence if we again read "elementary" as being "fundamental," which particles are fundamental depends on the perspective adopted. Of course, as McKenzie notes, we have as yet no evidence for magnetic monopoles (2017a), so this duality remains conjectural (as do indeed string theory and associated dualities in general), but as a physical possibility, it represents a further challenge to standard views of fundamentality, generating claims that which particle is taken to be fundamental should be seen as being only as a matter of computational convenience.

Of course, one must be careful not to be too hasty in making such assertions since it can be argued that the computational convenience is in fact facilitated by, rather than underpinning the relevant fundamentality claims (McKenzie 2017a, p. 8). Nevertheless, duality raises some interesting issues: with the electric and magnetic charge couplings as constants, each permitted pair of values defines a different model of the theory. Thus we get a whole spectrum of possible scenarios as these values vary – in those scenarios where the charge coupling is small we may regard electrons as fundamental and in those where the magnetic charge is small, it is the monopoles that are fundamental. And indeed, to any scenario of the former kind, there will correspond a scenario of the latter kind. But these, of course, are scenarios that lie at the ends of the spectrum, and in between, there are scenarios for which the couplings are comparable – in these scenarios we have to say that there are no fundamentality facts at all (ibid., p. 9). Thus, duality offers another physical possibility encompassing a non-fundamental ontology.

The upshot, then, is that the status of the "received view" of fundamentality must be evaluated against a background of relevant theoretical assumptions, both physical and metaphysical (see McKenzie 2017a).

49.3 Populating the Fundamental

Let us now turn to the second question, namely, what is it that we take to populate the fundamental level?

Much of the discussion around the "received view," particularly in the metaphysics literature (for an overview, see for example, Tahko and Lowe, 2016, esp. section 6.4; a useful

critical survey can also be found in Schaffer, 2003), take those entities that are designated as "fundamental" to be particles, typically understood in a broadly classical sense; i.e., as little lumps of "stuff," banging into one another and which compose other, derivative entities in accord with some set of mereological principles. However, this is precisely the kind of "high school" metaphysics that the likes of Ladyman et al. (2007, Ch. 1, esp. section 1.6) dismiss as utterly inadequate in the context of modern science. And indeed, as we've already seen, Callender has also noted in this precise context that this crude "particle picture" just won't wash these days and that when physicists talk of "particles" it is shorthand for field quanta (op. cit.; and as is well-known, extracting a robust particle metaphysics from quantum field theory is beset with difficulties; see Wallace (this volume) and Fraser (this volume) for details of conceptions of particles as non-fundamental in QFT). Placing fields at the fundamental level might seem to raise concerns for the fundamentalist, given that they are characterized by an infinite number of degrees of freedom but as Callender remarks, that they offer a "horizontal" infinity does not imply a "vertical" one and hence there is no obstacle to a field-theoretic "bottom" layer in some hierarchy (Callender 2001). Of course, that still leaves the further issue of how that hierarchy composes (as McKenzie notes, we can still find a distinction between fundamental and derivative fields within the QFT framework; 2011, fn 9).

However, *that* issue is resolved there is another that bears more directly on the fundamentalist thesis. Quantum fields evolve according to "unitary" dynamics. This means that the dynamics is linear (and hence states enter into superpositions) and "norm-preserving," in that the relevant probabilities sum to 1. It then follows that the fundamental laws will be those that continue to hold and retain that unitary nature even at the smallest spatial scales and hence the highest energy scales – indeed, even as the energy tends to infinity. Satisfying that requirement in general turns out to be hugely tricky, but it can be met in the case of a certain class of theories, namely those that are "asymptotically free" in the sense that the interaction couplings (which encode the strength of the interactions) upon which the relevant probabilities depend, tend to zero as the energy goes to infinity. It then turns out that asymptotically free theories cannot incorporate either too many kinds of fields or too few (see Coleman and Gross, 1973; Gross and Wilczek, 1973).

Thus in the case of quantum chromodynamics (the QFT applicable to the strong nuclear force), there can be no more than 16 kinds of fermionic field (the quarks) and 8 bosonic (see above). Generalizing this, McKenzie argues that if we take the fundamental *kinds* in the world to be given by the types of quantum fields, then a "Goldilocks Principle" holds, according to which there must be some number, greater than zero, of bosonic fields (strictly, non-Abelian gauge bosons), some upper limit on the number of fermionic fields and those two numbers must

be related (2017b). As she goes on to note, this is a highly significant constraint on the fundamental kinds that there are. But then, if such a constraint can be understood as, at least, a partial explanation, then it cannot be the case that what kinds are instantiated in the world is a "brute" fact, in the sense of that which requires no further explanation. And if such a fact cannot be considered to be "brute," then, the argument goes, the associated kinds cannot be regarded as fundamental.

Now, of course, as McKenzie notes, there are various ways in which the advocate of the "received view" can try to avoid such a conclusion. She might, for example, draw on Humean metaphysics which insists that all there is to the world is a mosaic of modally unconstrained facts, with statements of laws, symmetry principles, and the like understood as mere descriptions of regularities in this mosaic. Thus she could insist that such principles as unitarity, while regarded as "constraints" by physicists themselves, have no such force metaphysically speaking and thus should not be understood as explanatory. That may seem a high price to pay for many, particularly given Humeanism's other problems in accommodating scientific practice (Hall, 2015).

Alternatively, she might argue that such partial explanations have no place in metaphysics but given that our identification of quantum fields as the fundamental entities already commits us to some form of naturalized metaphysics, it might seem odd to reject out of hand in our metaphysics that which has explanatory force in our best science. Finally, and relatedly, she might simply insist that the fundamental should not be characterized in terms of the explanatorily brute in this manner. Thus Barnes (2012) has argued that the distinction between the fundamental and the derivative should be "pulled apart" from that between the ontologically dependent and independent. (This allows her to propose an understanding of emergence in terms of that which is ontologically dependent yet also fundamental.) If ontological independence is identified with being explanatorily brute, then this might offer a framework in which one could accommodate entities that are deemed to be fundamental but are not the ultimate explanans. But then, that would generate a curious kind of "disconnect" with fundamentality's characterization in terms of that which has ontological priority, say, since typically if x is ontologically prior to y one would expect consideration of the behavior of x to feature in the explanation of the behavior of y.

Of course, there is more to say on all of the above but at the very least, a tension arises between the core precepts of QFT and what seems to be a plausible feature of fundamentality. One option would be to retain that feature and insist that the fundamental should be identified with the "ultimate" explanans; that is, the fundamental level is populated by whatever explains

the occupants of the hierarchy above it. Now, as McKenzie makes clear, her Goldilocks Principle and the unitarity that underpins it only offers a *partial* explanation, so the question arises: can we move toward something more complete?

Perhaps we can. Consider the Standard Model, for example (strictly this is not asymptotically free but it may be asymptotically "safe" in the sense that the interaction couplings tend to finite values rather than zero). The role played by certain symmetry principles in generating this model is well-known and the nature of such principles, in particular, the way they may be seen to constrain the relevant laws, has been discussed quite extensively in the philosophy of physics literature (see Brading and Castellani, 2003). Here I want to focus on the point that certain so-called "fundamental" properties effectively drop out of such principles and hence it is the latter that should be regarded as fundamental, in the above explanatory sense.

Let us begin with "Permutation Symmetry" which effectively encodes the fact that it does not matter to the relevant measurement outcomes whether the particles of the system are permuted, or not.[2] As a constraint this divides up the state space into self-contained sectors, each corresponding to a certain fundamental kind of particle and yielding a particular form of quantum statistics, the two most well-known being fermions, which obey Fermi-Dirac statistics and bosons, obeying Bose-Einstein statistics (there are others, corresponding to so-called parastatistics which do not appear to be realized in nature). Thus, the most fundamental kinds that we considered above and into which the particle zoo can be divided, effectively drop out of the action of this particular symmetry. Secondly, the underlying framework of the Standard Model is, of course, QFT, which is a relativistic theory, so the second set of symmetries that needs to be considered are those of Minkowski space-time. These are the translations, rotations, and "boosts" that are captured mathematically by the Poincaré group and as Wigner famously showed (Wigner, 1939), this yields a classification of all "elementary" particles, in terms of their mass and spin. Thus these fundamental properties also effectively drop out of this particular symmetry.

Finally, the Standard Model itself is a gauge theory, represented mathematically by the group SU(3) × SU(2) × U(1). This gauge-theoretic aspect 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 (see Teh (this volume) for more details of gauge theories). The generator of this group of transformations represents a field and when such a field is quantized, we get the so-called gauge bosons, also mentioned above. Thus, consider electrodynamics, for example: here the relevant gauge symmetry group associated with the

property of charge is labeled U(1) and the requirement of gauge invariance yields a particular gauge boson, namely the photon. Thus, the photon also "drops out" of the imposition of this further symmetry. This requirement can then be extended to the other forces in physics and so, for the weak nuclear force, we have the SU(2) symmetry group associated with isospin, a property of protons and neutrons, and the strong nuclear force associated with SU(3) which operates on the color property of quarks.

Clearly, as indicated, these symmetries play a crucial role as part of the framework of the Standard Model and one can take that role to be explanatory. So, consider again the bosonic and fermionic kinds, which "drop out" of the Permutation Symmetry. Again, that "dropping out" can be read in an explanatory fashion, and again we have (at least) a partial explanation in McKenzie's terms. Likewise, we can offer an explanation of the core properties of the purportedly "fundamental" particles and even of the existence of the force-carrying bosons such as the photon. Taking these together, the partial explanations add up to at least something approaching a complete explanation of the kinds of particles we observe, their properties, and the relevant gauge particles by which they interact (there are still features and properties left unexplained, such as neutrino oscillations and their associated mass, for example).

Of course, one might ask for further details as to the type of explanation that is involved here but fortunately, recent work can be called upon in response: Lange has argued that he is able to incorporate 'explanation via constraints', such as unitarity and symmetry principles, into his framework of non-causal explanations, according to which explanatory power accrues from a form of necessity that is stronger than that possessed by laws of nature (Lange, 2016). French and Saatsi have suggested that Woodward's counterfactual account can be extended to these sorts of situations, as the different possibilities encompassed by these symmetries allow us to entertain "what if things had been different?" scenarios (French and Saatsi 2018). Thus, in this respect at least, there seems to be no obstacle regarding symmetries as explaining things. Now, of course, there is always an issue as to where one takes the explanatory "buck" to stop but one can argue that such symmetries – regarded as "meta-laws" that constrain the relevant laws, as they typically are in physics – should be understood as not themselves being candidates for an explanation. And if the fundamental is identified with the "ultimate" explanans, in this sense of that which itself is not up for explanation, then we should take these symmetries as populating the fundamental level.

Now, further concerns obviously arise. In what sense can a symmetry principle be regarded as a fundamental element of reality? This breaks down into two: In what sense can a

symmetry principle be regarded as a fundamental element of (physical) *reality*? In what sense can a symmetry principle be regarded as a *fundamental* element of (physical) reality?

Let us consider the first. Consider the equivalent question for laws: obviously if one is a Humean, then laws simply do not feature in one's metaphysical pantheon as noted above. But if one is not, if one feels that laws are instantiations of relations among universals, for example, or have some primitive status, or are part of the structure of the world, then it can be argued that they do have the requisite ontological status as elements of reality (see Lange (this volume) for more details of these different conceptions of lawhood). Likewise with symmetries, then, which Wigner, for example, regarded as meta-laws: ontologically they can serve as such elements. Indeed, a certain version of "Ontic Structural Realism" takes the structure of the world to consist of, or more bluntly, to *be* (in part) laws and symmetries, appropriately inter-related (French, 2014).

Nevertheless, one might still worry whether such principles can be considered *physical*. They are typically described mathematically via the formalism of group theory, as indicated above, and there is an easy slide from acknowledging that descriptive aspect to reifying the mathematics and understanding such principles as Platonic entities (see the debate between Cao and French and Ladyman in Cao, 2003; French and Ladyman, 2003). But such a slide should be resisted. One option is to identify the physical with the causal but causality is famously problematic, particularly in the context of modern physics (French and Ladyman, 2003; French, 2014 Ch.8; also Frisch (this volume)). An alternative is simply to insist that 'the physical' is that which can be related to empirical results, in some sense, where that relationship obviously needs careful spelling out (French and Ladyman, 2003; French, 2014, Ch. 8; McKenzie, 2014, p. 1100). Taking this line, symmetries can be regarded as physical since they yield determinate properties that can be measured directly or indirectly. Indeed, the further "part" of the structure of the world not mentioned in the brief characterization of Ontic Structural Realism above is the determinate properties (and associated measurement results) that effectively "pin down" the structure given by the laws and symmetries as the structure of the world.

Now let us consider the second question. This goes to the heart of how we should conceive of fundamentality. Again we recall that the "received view" holds that the fundamental level is occupied by the "basic building blocks" (whatever they are) with the "building" captured by some mereological framework. However Wilson has usefully compared that which should be considered as fundamental to the *axioms* of a theory (Wilson, 2014) and drawing on such suggestions, Tahko has argued that we should drop this mereological approach to fundamentality and instead base our account on the idea of "ontological minimality," in the

sense that the fundamental level should simply be taken to consist of ontologically minimal elements, with no commitment to any mereological framework (and here he specifically mentions the possibility of including symmetries at the fundamental level; Tahko forthcoming). The further question then is whether symmetries can be *minimal* in Tahko's sense and hence fundamental.

McKenzie thinks not. Focusing on the priority aspect of fundamentality she first argues that neither of the more obvious ways of capturing that aspect – via relations of supervenience and dependence, respectively – can do the job. Supervenience, she states, is simply not fit for purpose, whereas dependence places both symmetries and particles on an equal footing. We recall that the given symmetries are described via group theory and the afore-mentioned particle properties, or the kinds "boson"/"fermion," are represented mathematically by the relevant group-theoretic representations. The sense in which these properties and kinds "drop out" of the symmetry is precisely the sense in which a particular group's representations are derived from the group. But now consider the relation of supervenience, which holds that x supervenes on y iff *necessarily*, differences in x entail differences in y: for the particle properties to supervene on the symmetry, then, the former would need to be instantiated in every possible world in which we have the latter. However, not all of the possible representations and associated properties are instantiated in a given world, such as this one (there is an infinite number of "paraparticle" representations associated with Permutation Symmetry, for example, that are not manifested in this one!). Hence the particle properties and kinds do not supervene on the symmetries and the latter cannot be considered to be prior, in these terms, to the former (Wolff, 2012; McKenzie, 2014, p. 1097).

Now consider dependence: clearly, the representation is dependent on the group, since the former is given by and obtained from, mathematically, the latter. Since the relevant representation is then taken to capture the associated properties and the group represents the relevant symmetry, one can conclude that the properties must be dependent on the symmetry. But recall what was said above: for that symmetry, represented group-theoretically as just noted, to be regarded as *physical*, it must yield determinate, measurable properties, *via* the relevant representation. Hence the reference to the latter cannot be avoided if the given symmetry is to be taken to be more than just a feature of mathematics and a fundamental element of physical reality. In that sense, then, particle properties and symmetries (conceived of as physical) must be taken to be on a par ontologically (McKenzie, op. cit., p. 1101).

Perhaps there is some alternative device in the "toolbox" that will do the trick. It has been argued, for example, that the relation between symmetries and properties or kinds should

not be understood as one of dependence but that of determinable-determinate (French, 2014, Ch. 10). Thus, for example, Permutation Symmetry can be taken to be the relevant determinable and the bosonic kind, as represented by the appropriate irreducible representation, one of that determinable's determinates, just as "scarlet" is a determinate of the determinable "red." Now there might be an immediate objection that the occupants of the fundamental level must be determinate, and so determinables cannot be fundamental, but it is hard to defend that line in a non-question begging manner and Wilson (2012) has argued that determinables are in fact perfectly acceptable as fundamental features of reality.

However, that doesn't resolve the above issue of priority. Consider: a world with only determinables in its fundamental level would be a modally indeterminate world. A world that just had Permutation Symmetry as fundamental, would be one with the possibility, but never the actuality of course, of the infinite number of different kinds of particles that are allowable. To remove that indeterminacy and obtain a specific possible world we need to incorporate the requisite determinates as well – bosonic and fermionic in the case of the actual world (French, 2014, p. 285). One can think of such determinates as "existential witnesses" in this sense of yielding a specific possible world (Wilson, 2012). But that means, of course, that both the relevant symmetries and certain representations – and hence certain particle kinds and their properties – must be included in the fundamental level (French, op. cit.).

49.4 Conclusion

Where does this leave us? Clearly, the "received view" with its basic building blocks lying at the seat of some physical hierarchy ordered according to standard mereological principles has come under threat. The nature of such elements, as given by modern physics, forces a revision that expands the fundamental level to include symmetry principles (and laws). Of course, one might still try to insist that once we get beyond that level, the standard picture returns but a simple reflection on the role of Permutation Symmetry in chemical bonding, for example, dashes that hope. Still, given that we should be committed to a naturalistic metaphysics, this is all exactly as it should be – we (metaphysicians as well as philosophers of science) should pay attention to the results of modern science, not least in the form of our "best" theories, when we consider such issues. However, that does not mean eschewing the results of metaphysical thought. Specific devices such as that of "determinable" as well as more general maneuvers such as shifting to a notion of ontological minimality can be regarded as tools to be appropriated in articulating an account of what it is for something to be "fundamental" that is both scientifically sensitive and metaphysically nuanced.

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Further Reading from the Editors

A. Ney "The Politics of Fundamentality," in A. Aguirre, B. Foster and Z. Merali (eds.), *What Is Fundamental?* (Springer: 2019) is a nuanced discussion of the role of the concept of fundamentality in the political case for physics funding. E. Adlam, "Fundamental?", in A. Aguirre, B. Foster and Z. Merali (eds.), *What Is Fundamental?*, (Springer: 2019) challenges standard assumptions about the necessity of a fundamental lowest physical level. For the state of the art in the general metaphysics of fundamentality, see T. Sider, *The Tools of Metaphysics and the Metaphysics of Science* (Oxford: Oxford University Press, 2020). For skepticism about both a priori and naturalistic metaphysics of the fundamental, see K. McKenzie, "A Curse on Both Houses: Naturalistic versus A Priori Metaphysics and the Problem of Progress," *Res Philosophica* 97(1), (2020): 1–29.

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[1] See Dizadji-Bahmani (this volume) for discussion of the concept of reduction.
[2] See Caulton (this volume) for more details on permutation symmetry and identity; also French and Krause (2006).