On the Fundamentality of Symmetries

Kerry McKenzie*

1 Introduction

That symmetry is fundamental to modern physics is a view frequently expressed by physicists. In his popular expositions Steven Weinberg, for example, has aimed above all to communicate his conviction that 'symmetries are fundamental, and possibly all that one needs to learn about the physical world beyond quantum mechanics itself'.[1] His fellow particle physicist Abdus Salam has argued similarly that it is 'not particles, but principles of fundamental applicability that are elementary to all of nature', underlining that these principles are typically symmetry principles.[2] Werner Heisenberg was likewise explicit in his view that modern physics compels us to 'replace the concept of a fundamental particle' by 'the concept of a fundamental symmetry', and that 'all we need to look for' are the latter.[3] In fact, the view is by now sufficiently widespread for it to be asserted that 'any physicist would agree that symmetries are fundamental in contemporary physics', and this stance on the status of symmetries to the expense of particle is shared by many philosophers of physics as well—notably, the ontic structural realists.[4]

Clearly, then, the idea that symmetries ought to be regarded as fundamental thus enjoys wide support and has some distinguished adherents. And it seems flatly undeniable that throughout the twentieth century symmetry has indeed played a fundamental role both *qua* heuristic device for theory construction and as a tool for predicting new particles, whether it be the celebrated prediction of the Ω^- in 1964 or the Higgs boson detected last year.[5] But while it

*Kerry McKenzie, Department of Philosophy, University of Calgary, Calgary, AB T2N 1N4, Canada. Email: mckenzie [underline] kerry@ymail.com

[1]Weinberg and Feynman (1987), 79.

[2]This is Weinberg's ((1993), 44)) concise rendering of Salam (1979), 528.

[3]Heisenberg (1975), 393-4.

[4]Henri-Couannier (2005); italics added. On ontic structuralism, see e.g. Ladyman and Ross (2007), especially Sec. 3.3 and references.

[5]For a general survey of the role of symmetry in the twentieth century – often aptly dubbed the 'century of symmetry' – see Martin (2003).

is clear that symmetry has been fundamental with respect to both the generation of theories and the prediction of particles, it also seems clear that at least some of the protagonists above want to claim more than that symmetries are fundamental in these *methodological* respects. Rather, they want to claim that they are fundamental to *nature*, and in particular, they want to assert that symmetries are more fundamental to the fabric of the world than even the so-called elementary particles. Such a claim on behalf of symmetries is clearly an ontological one, and moreover a highly revisionary one. But while the claim circulates, in various forms, in the physics, popular physics, and philosophy of physics literature, comparatively little has been written on either what we should ultimately take it to mean or whether it can be rigorously defended. In what follows, I will try to address that lacuna by considering, first, what it means to say symmetries are more ontologically fundamental than elementary particles, and then whether there are good grounds for holding this to be the case.[6]

2 Conceptions of Relative Fundamentality

Our first task, then, is to make explicit what it is that we mean when we confer fundamentality on something. In particular, we must consider what it is that we intend when we designate something as *more ontologically fundamental* than something else, or – as it is often put – *ontologically prior*. This question of how to conceptualize ontological priority is clearly a metaphysical one, and as such we might look to the metaphysics literature to try to gain a purchase on it. When one does so, however, it rapidly becomes clear that there is no univocal way of understanding the notion, for two classes of relation are frequently invoked to articulate priority claims. On the one hand, we have the relation of *ontological dependence*, where we may say (to a first approximation) that x ontologically depends upon y iff necessarily, the existence of x entails the existence of y. This is the understanding of relative fundamentality typically invoked, for example, when we say that a composite is less fundamental than its parts.[7] Since the ontological dependence of x on y entails that x cannot exist without y existing as well, when we articulate priority in terms of dependence we present the fundamental as a *necessary* condition on the non-fundamental. On the other hand, however, we have the relation of *supervenience*, where we may say (to a first approximation) that x supervenes on y iff necessarily, differences in x entail differences in y. This is the relation most often invoked when it is said that the mental or the moral is less fundamental than the physical. Since when we construe of priority in supervenience terms we commit to the assertion that fixing the fundamental is enough to fix everything else, supervenience presents the fundamental as that which is *sufficient* for the non-fundamental.

These two relations of dependence and supervenience are frequently deployed to express relative fundamentality claims. But it will be clear right away that they are conceptually quite distinct, presenting the fundamental as that which is necessary, and that which is sufficient, for

[6] Here and throughout, those sceptical of the existence of particles may replace ‘particles’ by ‘fields’, for as far as I can see nothing crucial for present purposes is affected by the replacement.

[7] Whether a purely modal construal of dependence is adequate is disputed. I touch on this again below.

the non-fundamental respectively. Indeed, I would go further and claim that these two relations not only are conceptually distinct but moreover non-coextensive, and therefore that they are capable of delivering conflicting results regarding what is ontologically prior to what.[8] It follows from that that if we accept that both of these relations represent legitimate ways of conceiving of relative fundamentality – and it is unclear to me, at least, why we should not – then an abstract claim of ontological priority is simply ambiguous as it stands, and some one relation must be specified before we can assess it. It follows furthermore that unless we can find, in any given context, some principled reason to regard one relation to the exclusion of the other as the appropriate relation to cite – though again, it is unclear to me on what grounds we could do so – then claims of relative fundamentality will themselves be irreducibly relative. As such, there may simply be no absolute answer to questions of what is more fundamental than what in this world.

These questions of whether we can expect there to be some one priority relation that is most appropriate to cite in any given context, and what the metaphysical structure of the world would be if turns out to not be the case, pose deep and challenging issues for anyone interested in fundamentality metaphysics. Nevertheless, they are not questions I can do any justice to here. To recap, the claim we set out to assess is whether we can regard symmetry as more ontologically fundamental than even elementary particles. To keep things simple, let us just take it that this claim will have been shown to be true if it can be shown to be so *on at least one* of the above renderings of ontological priority, simply bracketing for now the question of what to say in the face of any conflict between the two relations on this score. That is, if we can show that particles either supervene *or* ontologically depend on symmetry, but not *vice versa*, then we will take ourselves to have established the view outlined above on the ontological status of symmetries.

Our investigation into priority in particle physics will begin by thinking about how symmetries stand to particles in terms of supervenience; from there, we will consider the situation with respect to ontological dependence. In order to evaluate these metaphysical relationships, however, we must first acquaint ourselves with the relations between symmetries and particles from a physical and mathematical point of view. We turn to that now.

3 The 'Group-Constitution' of Particles

As already noted, the ability of symmetry conjectures to furnish successful predictions about what particles we can expect to discover makes it virtually impossible to deny that symmetries have a fundamental methodological role to play in contemporary physics. But by examining the facts that make those predictions possible we can try to recast the situation in suitably ontological terms. The crucial concept that does the work in each case is that of the *irreducible*

[8] For example, the possibility of multiple supervenience suggests that there may be relations of supervenience without corresponding relations of ontological dependence. Conversely, similarly to the way that Cartesian attributes depend on extension without supervening on it, entangled state relations arguably depend on certain properties of their relata even while they (famously) fail to supervene on them. I discuss all this more thoroughly in a longer paper (still in preparation).

representation of a symmetry group, and blurring out most the mathematical details we can explain this concept as follows. To say that there is a 'symmetry in nature' is typically to say that there is a symmetry in the *dynamics* describing the portion of nature in question. To say that is to say that the laws there operative are invariant under the action of a group of operators, which in quantum mechanical parlance is to say that the Hamiltonian describing the dynamics commutes with each operator in the group. In quantum frameworks these operators are typically matrix operators, giving rise to *matrix representations* of the group, and of particular interest are the so-called *irreducible* representations that may be defined by means of these matrices. A characteristic feature of irreducible representations – or, for brevity, 'irreps' – is that when the associated matrix operators act in a vector space, the vectors of that space are mapped into one other in such a way that there is no proper, non-trivial subspace of vectors all of which are mapped into one another under the action. Such sets of vectors are said to form *irreducible invariant subspaces*, and it may be shown that two such subspaces corresponding to two different matrix irreps are always disjoint. These disjoint vector spaces (and indeed the irreps themselves) may be characterized by the values of the r invariant or 'Casimir' operators that can be defined for each Lie group.[9]

These irreps play a pivotal role in particle physics, and the reason that physicists are interested in them in particular is a function of both their mathematical properties and their physical interpretation. The irreps of a group are prime objects of study from a mathematical point of view on account of the fact that, for any compact group, any representation may be expressed as a sum of irreps, making the latter the 'building blocks' of representation theory in both a precise and a general sense. With regard to the physics, however, the significance of the irreps can vary with the physical context. For concreteness, let us focus on the symmetry groups involved in the Standard Model (clearly an appropriate choice, given the question at hand). The symmetries of this model may be divided into two classes: the 'external' symmetry describing the free motion of particles in spacetime, and the 'internal' symmetries describing their interactions through the three fundamental forces that the Standard Model accommodates. Regarding the first class, the relevant symmetry group is the Poincaré group, whose transformations correspond to transformations between inertial observers. Partly on account of the fact that the operators involved here themselves have a clear physical interpretation, a clear physical meaning can be also ascribed to the associated irreps in the following way. Owing to the disjointness, the vectors in the two invariant subspaces corresponding to any two distinct irreps of the Poincaré group cannot be mapped into one another by the action of the operators. As a result, any differences between the vectors in these respective spaces cannot be effaced by mere changes in an observer's perspective, so that any such differences may be regarded as real and objective. But it turns out that the Casimir operators that label these spaces are given by functions that may, in the context of special relativity, be taken to be equal to mass and spin.[10] Each different irrep thus corresponds to a different pair of determinate values for these properties, where in the case of mass this may be shown to be any $m \in \mathbb{R}_0^+$, and in the case of spin any $s \in \mathbb{Z}/2$.[11] As such, a continuous infinity of different irreps are associated

[9] Lie groups are those with continuous parameters, and our focus will be on these.

[10] More precisely, the *square* of mass, and in the case of massless particles the 'spin' is really the helicity.

[11] Or integer when helicity is concerned. I note further that some irreps of the Poincaré group are excluded from

with this group. Since species of particle are defined in terms of their different concatenations of determinate properties, and since the differences between these sets of properties can be interpreted as real and objective, it is natural to take the invariant subspace defined by each irrep of the Poincaré group to correspond to a different species of relativistic particle. It was in fact in just this way that the connection between symmetries and elementary particles was born.

Let us refocus now on the groups corresponding to the interactions between particles. Here we find that the situation is somewhat different, both in terms of the mathematics and its interpretation. The SU(2) and SU(3) gauge symmetry groups in the Standard Model (associated with the weak and strong interactions respectively) are both simple (hence semi-simple) Lie groups (the U(1) group associated with electromagnetism is not semi-simple but nevertheless has a rather trivial representation theory). This means that we can deploy the machinery associated with semi-simple Lie algebras to study both them and their representations. What one finds upon doing so is that each of these groups' irreducible representations has an associated *weight diagram*, where each weight in the diagram is defined by a set of eigenvalues of the generators of the r operators in the group that commute not only with the Hamiltonian but also with each operator in the group. As these generators can (for unitary groups) always be chosen Hermitian, these sets of numbers that define a given weight may be regarded as a set of simultaneously possessed determinate properties. And since, to repeat, we identify particle species in terms of such sets of properties, we have grounds to regard each weight in the diagram as corresponding to a possible species of particle. Finally, since weight diagrams generally contain a plurality of weights, the irreducible representations of semi-simple Lie groups may thus be taken to correspond to *families of particles*. Two examples of such families are shown below.

Weight Diagrams and Particles.

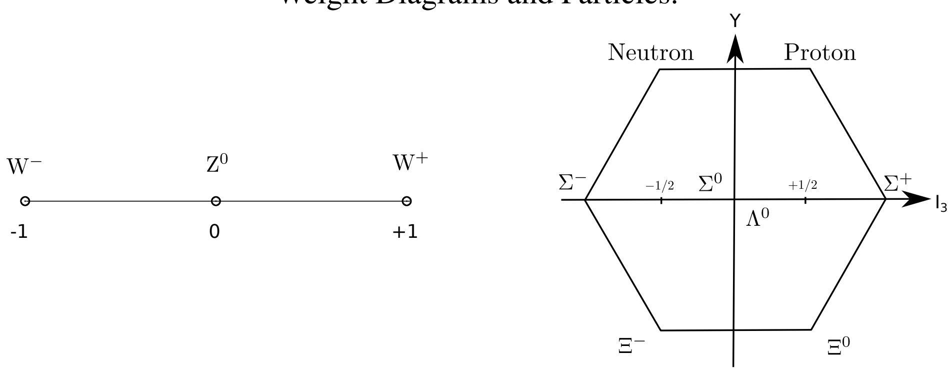

Figure 1: On the left, SU(2) triplet of weak bosons, arranged on axis of weak isospin; on the right, SU(3) octet of hadrons, arranged against axes of strong isospin and hypercharge.

The members of these families are similar to each other in virtue of possessing the same Poincaré-group properties (at least to a first approximation in the case of mass), as well as the same determinable 'internal' properties that mark the axes of the diagrams above. But they are

consideration on grounds of causality, but I omit the details here.

nevertheless distinguishable from one other in virtue of their taking on different determinate values of those determinables. Just as in the case of the Poincaré group, there are infinitely many irreps of these groups that may be defined, and hence in principle infinitely many possible families of particle permitted by each of these groups (though the infinity in this case is countable). I note finally that the elegant geometric symmetry of these diagrams is a visual manifestation of the symmetry of the dynamics themselves.

The above story gives just the barest outlines of the relationship between symmetries and particle species in modern particle physics. Nevertheless, it should be enough to make clear that the full story will place the irreducible representations of the relevant symmetry groups absolutely centre-stage. We have seen enough in any case to know that positing a symmetry at work in the dynamics allows us to deduce some highly non-trivial constraints upon what sorts of concatenations of properties – what sorts of particles – we can expect to discover, and it is ultimately this fact that has allowed 20th century physicists to correctly predict, again and again, the existence of then unseen particles. In fact, the success of these predictions has not only corroborated the formal assumptions underlying the symmetry-particle correspondence, but also encouraged the *metaphysical* idea that the particles of modern physics ought to be regarded as 'constituted' by symmetries in some profound sense. One may thus find contemporary physicists saying things like 'an elementary particle "is" an irreducible representation of the group, *G*, of symmetries of nature' – a claim which voices just how tightly enmeshed the modern particle concept is thought to be with the concept of symmetry.[12]

Such claims as to the identity and constitution of the objects of physics clearly go beyond the unvarnished mathematics, and we feel correspondingly less secure about them. Indeed, these claims to how objects are 'constituted' or what they 'are' typically have the operative word in scare quotes, and it is not difficult to see why things are hedged in this way. For one thing, given that any irreducible invariant subspace corresponding to a (non-trivial) irrep of the Poincaré group will contain empirically distinguishable states, where this distinguishability cannot be effaced by a change in observers, it is clearly not at all straightforward to conceptualize how a particle could be identified with an irrep in a literal sense; for presumably at any given moment the particle is in *at most one* of these states.[13] Given this coexistence of empirically distinct properties in one and the same irrep, if objects are to be 'constituted' by symmetries then clearly the metaphysical story must be much more conceptually and modally complicated than the familiar (if somewhat unilluminating) story of how car tyres are supposed to be 'constituted' by the concatenation of black, round and rubber tropes.

But complicated does not mean unfeasible. While I cannot speculate here upon all the subtleties that are likely to be involved in the final analysis, let us accept for present purposes that the symmetries revolution in particle physics at least *suggests* that we have to conceive of the nature of particles in a radically new way, a way in which the notion of irreducible representations somehow enters into their very definition. Granting this much, let us move on to consider

[12]Ne'eman and Sternberg (1991), p. 327. On the constitution of objects by symmetries, see Castellani (1993).

[13]To see this, consider that, for any momentum state p and a Poincaré transform of it p', the invariant subspace corresponding to a Poincaré group irrep will contain the vector $v = p + p'$. But v is empirically distinct from both p and p' (just consider an ensemble of such particles), and since v cannot be obtained from either p or p' via a Poincaré transformation the difference cannot be effaced by changing observers.

the question under consideration regarding the fundamentality of symmetries, examining the question through the lens of supervenience first.

4 Symmetries and Supervenience

Couched in supervenience language, to say that symmetries are ontologically prior to particles is to say that the particles supervene on symmetry without the symmetry supervening on them. As noted, a supervenience claim is essentially a claim about determination: by saying that particles supervene on symmetry, we commit to the idea that by settling the symmetry at work in a world we do enough to settle its particle content. But given that this is what supervenience amounts to, even the cursory outline of the mathematics above suffices to show that particles do not supervene in this way. The reason for this is straightforward, and stems from the fact that while particles are certainly associated with the appropriate symmetry group via the latter's irreducible representations, the symmetry – irreps relationship is very much *one: many*. We noted, for example, that there is an irrep of the Poincaré group for every real value of mass greater than or equal to zero, and for each one of those there are a countable infinity of representations corresponding to each permitted value of spin; but we clearly do not think that all of these representations are in fact realized in nature. Rather, we believe that only a handful of them are. It therefore seems perfectly consistent from a physical point of view that there should be another possible world that, like this world, possesses a Poincaré symmetry but is such that, instead of containing electrons, it contains particles with the same mass as electrons but spin 3/2. Or similarly, it seems perfectly consistent to imagine a world which didn't contain the electron neutrino, but contained a particle just like it but for a small change in its mass. And if that is the case, then it seems we have no choice but to admit that we can change the particle content of a world while keeping the symmetry the same; and that is just another way of saying that the particle content of a world does not supervene on symmetry.[14]

It therefore seems that if we cash out priority in supervenience terms then – *pace* the claims made by Weinberg *et al.* above – we cannot in general claim that symmetries are more ontologically fundamental than particles. It is simply not the case that by settling the symmetry in a world we do enough to settle its particle content. But in fact a case can be made that things are actually even worse than this, for one can – at least in some important cases – argue that the situation is *exactly the reverse* of that under investigation here. Consider again the weight diagrams illustrated above. As noted, each of these diagrams corresponds to an irrep of the relevant semi-simple Lie group, and the symmetry structure of the diagram itself reflects the underlying dynamical symmetry. But it is easy to show that the geometric structure of these weight diagrams is sufficiently distinctive of the corresponding symmetry to pin down what that symmetry is.[15] This is because each such diagram corresponds to *one and only one al-*

[14] This has also been noted by Wolff (2012).

[15] At least if we characterize the symmetry up to the level of the algebr. The algebra is admittedly a less fine-grained way to characterize a symmetry than the corresponding group, since the algebra is insensitive to the group's global properties. However, particle physicists are almost always interested in the local properties, so that determining the symmetry up to the level of the algebra only is nevertheless highly non-trivial.

gebra.[16] It follows from that, of course, that when it comes to those symmetries that may be described by semi-simple Lie algebras, it is not the case that the corresponding particles supervene on the symmetry but rather the other way around. And given that semi-simple Lie algebras are the norm in particle physics, we can only conclude that if we conceptualise priority in supervenience terms then the ontological priority of symmetry is pretty much dead in the water.[17]

5 Symmetries and Ontological Dependence

Supervenience has proved to be a non-compliant priority relation for securing the fundamentality of symmetry. But we have already established that there is more than one way to skin a cat when it comes to relative fundamentality, and we have elected for simplicity's sake to take symmetry to be prior to particles if it can be shown to be so on at least one rendering. Let us therefore turn out attention to how symmetry fares when we conceptualize priority in terms of dependence.

As already noted, to say that some entity x depends on y is to say, at the very least, that the existence of x necessitates the existence of y.[18] To consider whether particles depend on symmetries in this sense, we must consider what it is that is entailed by the existence of particles, and that is going to require us to think about what the natures of these entities are from the perspective of modern physics. And while we did not pretend to have the wherewithal to fill in all the relevant metaphysical blanks, we did concede that there is at least a case to be made that the particles of modern physics ought to be conceptualized in a way that makes ineliminable reference to irreducible representations. But if that is right, then it is clear right away that if they are indeed to be defined, at least in part, in terms of the relevant irreps, then an ontological dependence of particles on symmetries will be automatically generated. This is because the irreps of a group are themselves defined, as a straightforward mathematical fact, in terms of the symmetry in question, and it seems as clear as anything is in this domain that an entity cannot exist in the absence of whatever enters into its definition. On these grounds, I think we can cautiously say that there is indeed case to be made that particles, conceptualized *á la* modern physics, cannot be regarded to exist without symmetries, and in this way the ontological dependence of particles on symmetries is derived.

[16] Briefly, the weights in a weight diagram of a given algebra are separated by *root vectors*, where these root vectors define the algebra uniquely. The weights in the diagrams corresponding to two different algebras therefore cannot conincide with one another.

[17] They are the norm in part because they are the only class of symmetries that have a completely generic representation theory.

[18] I add the qualifier 'at the very least' here because metaphysicians are increasingly of the belief that purely modal analyses are too course-grained to do the work that fundamentality attributions are supposed to do. However, as many of the counterexamples to the modal analysis exploit necessary existents, it is unclear to me at present that a modal analysis is inadequate for conceptualizing the dependence claims we want to make in *physics*. In any case, we can regard the modal analysis as, at the very least, a first approximation to how dependence ought to be conceived.

So far, so good for those who would defend the ontological priority of symmetries. But we are not done yet, for unless we want to impose *a priori* that dependence relations are asymmetric – an imposition that I would argue is totally contrary to naturalism – we need to investigate the possibility that the dependence of particles on symmetries is reciprocated. But this, it turns out, is not such an easy thing to do. The reason it is not easy is because in order to assess the ontological dependence of symmetries on particles we need to be in a position to state what it is that the existence of symmetries entails; but what it is that we even mean by 'the existence of symmetries' is surely less than maximally perspicuous. Until we have a firm purchase on that we cannot make much progress here. But let's see how far we can get on the basis of what we do know.

The first thing to remind ourselves of is that, when we claim that symmetries are 'elementary to nature', we must mean that symmetries are to be thought of as somehow *more* than mere mathematical abstractions: the claim posits symmetries as denizens *of the natural world*, not abstracta dangling listlessly on the Platonic shelf. We must therefore clarify what it means to characterize symmetry as a *bona fide* physical entity in order to proceed. The next thing to underline is that, given that the current context is that of contemporary particle physics, one way of characterizing the physicality of a symmetry that might initially have seemed tempting is in fact expressly precluded. That is, while one might well have suggested that what makes a group physical as opposed to merely mathematical is that its operators enjoy a clear physical interpretation, we must bear in mind that the internal symmetries of the Standard Model are implemented as gauge symmetries. Given that the corresponding operators arguably have no physical interpretation at all, this seemingly obvious strategy seems to be precluded from the outset.[19] So we will need to think again about how to characterize symmetry *qua* robustly physical entity.

Let us therefore consider what strategies of capturing the physicality of symmetries have already been deployed in the literature. As mentioned, the idea that symmetry should be regarded as ontologically fundamental is a characteristic belief of ontic structuralists, and as such they have had to deal repeatedly with the issue of how to reconceptualize something so seemingly abstract as maximally ontologically robust. In this connection, French and Ladyman (2003) have said that the structures they have in mind as the fundamental constituents of nature are distinguished from their purely mathematical counterparts in terms of their being *causal*. But while symmetry structure is top of their list when it comes to structures of ontological import, I think that it would be nice, for all sorts of reasons, not to have to appeal to causality in order to underwrite this robustness. Amongst other concerns, though many of us are happy with the meaning of causal *statements*, it is entirely unclear that the idea that causes are part of the world is any more perspicuous than the idea we are currently attempting to illuminate.

Fortunately, however, I think that we can say something in the spirit of French and Ladyman that is nevertheless less problematic. Surely a more shorn-down, and uncontroversial, notion of physicality lies not in causation but in the having of *empirical consequences*. (One need not be a crude verificationist to admit that if something has no observable consequences

[19]See references in Martin (2003).

whatsoever then it cannot be part of the ontology of physics.) And to say that something has empirical consequences of course implies some connection to *measurement*. Now, I take it to be clear that measurement always involves the measurement of some *determinate property*: as is made explicit in the measurement postulate of quantum mechanics, one never measures properties *simpliciter* but rather their quantitative values. But now it is clear that if we are to empirically get a handle on the symmetries of particle physics then we need the particles in the picture: for it is the *representations* of the symmetry groups that are associated with determinate physical properties, not the groups themselves. It is the irreps of the Poincaré group, for example, that possess determinate mass and spin; the Poincaré group itself does not. (It clearly doesn't make sense to ascribe mass and spin to a set of transformations between observers.) Likewise, it is the *states in* the irreps of the SU(3) flavour group that possess the determinate properties of strong isospin and hypercharge that define the hadrons in the second weight diagram above; the SU(3) group does not. Putting everything together, then, it seems that reference to representations must be included in the definition of group structure *qua* denizen of physical—hence empirical–reality, since it is only these that can furnish the required connection with measurement. And that definition, for just the same reasons as before, will generate a *reciprocated dependence of symmetries on particles*. If we conceptualize priority in terms of ontological dependence, then, rather than symmetries being more fundamental than particles the two seem to be on an ontological par.

6 Conclusions

We have seen that the view that symmetries are 'fundamental to all of nature' is a popular one, with many distinguished advocates. But to evaluate the truth of this claim we must frame it in terms of some explicit priority relation. Supposing for now that we bracket the question of which, if any, of the various construals of relative fundamentality is the most appropriate, we may say that symmetries may be regarded as more fundamental than elementary particles if they may be shown to be so on at least one such construal. But I have argued here that there is *no* such construal. The situation when it came to supervenience was seen to be simply hopeless. And while the situation was better when it came to ontological dependence, it seems that the most we can derive is that symmetries and particles are on an equal ontological footing.

The latter situation will not be surprising for anyone whose hunch is that physical symmetries cannot exist independently of physical objects – any more than that there can be laws of nature without anything to behave in accordance with them. I suspect that those who share these more nominalist tendencies will demand a fuller story about how we can even really attempt to make sense of symmetries as something prior to and abstracted from the *objects* of physics. While that is a question I cannot deal with here, I hope that this discussion has at least shown that we cannot be too careful about projecting the undisputed methodological priority of symmetry in particle physics onto our image of the world itself.

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