In Search of a Fundamental Level

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ABSTRACT

This paper concerns the puzzle about the existence of a fundamental level of reality. While it will be argued that there are some good reasons to think that there *is* a fundamental level, the primary contribution of the paper is methodological: the 'levels' metaphor, our means to inquire into the existence of a fundamental level (in terms of *a priori* and empirical methods), and the prospects of determining the nature of this level will all be discussed. Specifically, I will consider an argument from ontological dependence to the effect that there is a fundamental level. Input from physics in our search for a fundamental level will also be analysed, and it will emerge that a study of fundamental physical constants, such as the fine structure constant, and of certain physical principles, such as the Pauli Exclusion Principle, are of particular interest. Some emerging work in quantum mechanics will be considered as well, and we will see that the theory of loop quantum gravity may offer some support for the existence of a fundamental level.

I Introduction

There are three primary questions that this paper is concerned with. They are as follows:

1. Is there a fundamental level of reality?
2. If there is, how can we know that this is the case?
3. Can we know what this fundamental level is like?

I am inclined to defend a positive answer in regard to the first question, but I am perhaps more interested in the second, methodological question, as well as the third question which is closely related to the second. It is not the aim of this paper to conclusively settle the first question, but merely to examine whether there is any hope of settling it in the first place, and if there is, what kind of methods we can use to study it.

The presentation of this paper will follow the discussion familiar from a recent book by James Ladyman and Don Ross (2007). Ladyman and Ross argue that reality is not organized into levels in the first place and that we have some good reasons to think that there is *no* fundamental level (pp. 4, 53–7, 178–80).

In the second section we will attempt to show that there are plausible interpretations of the ‘levels’ metaphor, and in the third section an interpretation of levels in terms of ontological dependence will be formulated.

The fourth section is concerned with a potential argument for a fundamental level and contains a detailed analysis of each premise of the argument. Support from current physics will be discussed in some detail. There are two readings of the argument, a strong and a weak one. The weaker reading concerns fundamentalism regarding the actual world, whereas the stronger reading suggests that if the argument is correct, a fundamental level is metaphysically necessary for the existence of macrophysical objects. This paper is primarily concerned with the weaker reading of the argument, which suggests that a fundamental level is *physically* necessary, that is, necessary given the physics of the actual world.

In the fifth section the compatibility of fundamentalism and some recent work in quantum mechanics will be discussed. This will require some speculative discussion concerning the interpretation of quantum mechanics; it will be suggested that loop quantum gravity is the most promising option if we hope to find support for fundamentalism in quantum mechanics.

The expected outcomes of the paper are that the existence of a fundamental level is at least a viable metaphysical possibility, and that there is some hope to establish a methodology for the study of the existence and nature of this level.

II The 'levels' metaphor

Our inquiry begins with an analysis of the 'levels' metaphor itself: what do we mean when we say that reality is organized into levels? In philosophy, the classic account of a hierarchical, layered understanding of reality comes from Oppenheim and Putnam (1958). They suggested that the levels of reality are based on science and the hierarchy is manifested by a reduction: macrophysical phenomena will be reduced to microphysical phenomena as a part of a general physicalist reduction, and the levels metaphor describes this layered reductionism. Specifically, the entities of a higher level of reality can be reduced to their parts, i.e. entities of a lower level of reality, and in fact are already contained in the lower level. Therefore, all entities, as they ultimately reduce to the bottom, or fundamental level of reality, are already contained in it.

The Oppenheim-Putnam (henceforth OP) account has been almost universally rejected and hence we do not need to go into its details. An obvious worry is the reductionism built-in to the account, but there are other concerns: Ladyman and Ross reject it is because of its commitment to atomism, which they deny (2007: 47). More recently, there has been a surge of alternative accounts concerning levels (e.g. Poli 2001 and 2007, Symons 2008, Salthe 2009, Potochnik 2010, and Rueger and McGivern 2010). However, we should be careful not to confuse the ontological question concerning levels of reality, and the question concerning levels of interpretation or explanation (cf. Potochnik 2010). We are interested in the former question.

Some of the more recent accounts of levels are non-reductive and even deny the commitment to atomism that Ladyman and Ross find troublesome. One of these is the approach suggested by Rueger and McGivern, which takes the hierarchy of reality to be a sequence, not of entities, but of behaviours of entities. These behaviours, they claim, are not ordered according to spatial part-whole relations like in the OP account. Furthermore, Rueger and McGivern claim that their account is motivated by current physics:

> When physicists talk about levels, they often do not have in mind a mereological ordering of entities. Instead, what they describe is best understood as a stratification of reality into processes or behaviours at different scales. To describe a system's behaviour at a particular scale, we first specify a set of equations that represent the relevant features of the system at that scale. It is then the solutions to those equations—for instance, the integration of an equation over some time interval—that describe the behaviour of the system on that scale. Note that 'behaviour' is understood very broadly here as the distribution of properties of a system over space and/or time. (Rueger and McGivern 2010: 4.)

As Ladyman and Ross are opposed to the 'levels' metaphor in general, they would presumably not be satisfied with such alternative approaches either. They are not alone in questioning the metaphor, as at least John Heil (2003) has argued against it as well, although for very different reasons. There are also those who deny that there is a fundamental level, but accept the levels metaphor in some form, such as Jonathan Schaffer (2003), and Andreas Hüttemann and David

Papineau (2005).[1]

So, why exactly do Ladyman and Ross abandon the levels metaphor? One of their major concerns appears to be that ‘the standard way in which these levels are distinguished is according to size’, which is indeed the case in classic accounts, such as the OP account, as they assume atomism and take granularity to be the primary criterion for distinguishing levels. However, as we can see e.g. from the line suggested by Rueger and McGivern, the atomistic assumption is not crucial for the levels metaphor. The same appears to be true of another concern that Ladyman and Ross have: that the levels metaphor is not supported by current physics (2007: 193). Sympathetically to Schaffer (2003), Ladyman and Ross (2007: 53–7) contend that the ‘levels’ metaphor understood as a mereological structure ordered by part-whole relations fails as there is no good evidence for mereological atomism. Schaffer entertains three alternative options as well though, namely that the levels metaphor could be understood as a supervenience structure ordered by asymmetric dependencies, or as a realization structure ordered by functional relations, or, finally, as a nomological structure ordered by one-way bridge principles (p. 500). Ladyman and Ross offer arguments against the supervenience structure and nomological structure as well the mereological structure, but not against the realization structure. They argue that ‘[Quantum Mechanics] teaches us that Humean supervenience is false, and that all the properties of fundamental physics seem to be extrinsic to individual objects’ (2007: 151). Schaffer himself concludes that we should remain agnostic about the existence of a fundamental level, but one of the goals of this paper is to demonstrate that although the question is far from settled, there are some promising lines of research that may help to get us closer to an answer.

In any case, our options in terms of the levels metaphor appear to be broader than Ladyman and Ross assume. Motivated by this, a further interpretation of the levels metaphor which does not assume mereological atomism will be offered – this approach is also compatible with current physics. According to this proposal, levels can be interpreted as a sequence of ontological dependence.

III Levels as a sequence of ontological dependence

To begin with, something should be said about ontological dependence in general.[2] We will then consider some examples which suggest that it is plausible to analyse the structure of reality in terms of ontological dependence, and that this produces a natural hierarchy. Finally, it will be examined whether there are good reasons to think that the sequence of ontological dependence that we are dealing with here has a ‘bottom level’.

The idea that ontological dependence might help us to make sense of the fundamental level of reality, or of levels of reality in general, has recently been discussed for instance by Ross Cameron (2008) and Alexander Paseau (2010). If there is a fundamental level, it could be defined in terms of *ontological independence*, that is, the existence of anything in the fundamental level cannot depend on something else. The problem that we face in trying to make this conception of ultimate ontological basis serve the purpose that we hoped is that all the usual formulations of ontological dependence are inherently committed to entities, that is, to mereological atomism, which, as Ladyman and Ross as well as Schaffer have argued, is not satisfactory in the light of current physics. Specifically, according to the usual formulation of ontological independence, the fundamental level would consist of ontologically independent *entities* – presumably these would be fundamental particles of some sort. A modification to this account will be proposed towards the end of this section, so that we can remove the commitment to entities.

Another possible understanding of the fundamental level might be in terms of an atomless supervenience base, which is an option that Schaffer (2003: 509-512) briefly discusses. The idea of a fundamental supervenience base is that either there is a fundamental level of reality, or there is an infinite descent which is ‘boring’, i.e. the same structure repeats *ad infinitum* and the supervenience relations between all lower levels are symmetric – it's turtles all the way down. Schaffer thinks that this option is more interesting as well as more viable than the atomistic approach, but claims that it fails because, just as the atomistic approach, it requires that there will be a completed microphysics, and we have no support for this assumption. Schaffer observes that the history of science is full of examples of scientists (and philosophers) asserting that the end is near, only to discover that it was barely the beginning. However, there is no reason why the advocate of a fundamental supervenience base would have to commit to this premise. In what follows I will suggest that the best way to understand the 'levels' metaphor is in terms of a sequence of ontological dependence that terminates in a fundamental supervenience base.

The reason why Schaffer includes completed microphysics as a premise of the fundamental supervenience base approach is that he is looking for *a posteriori* arguments for a fundamental level; the idea is that establishing that there is a fundamental level would require completed microphysics. Because of this, Schaffer thinks that we should remain agnostic about the existence of a fundamental level insofar as *a posteriori* arguments are concerned. This may have the appearance of a pessimistic meta-induction: microphysics will never be completed because so far it has always turned out that there is further structure down the line. But while it would indeed be a mistake to rule out *a posteriori* evidence for a fundamental level – or for the lack of one – altogether, it will certainly be difficult to produce any conclusive empirical evidence one way or the other. Schaffer also dismisses some *a priori* arguments for atomism, but he does not even consider the possibility of *a priori* arguments for the supervenience base approach.

Interestingly, Brown and Ladyman (2009: 27) have asserted that, contrary to what Schaffer claims, physicalism is not committed to the requirement of a completed microphysics either, or even to the idea that it is completable in principle. In fact, they claim that this is an advantage of physicalism over atomism. Schaffer himself associates the commitment to a fundamental level with atomism, Humeanism[3], epiphenomenalism[4], and physicalism. Brown and Ladyman (p. 28), perhaps rather surprisingly given Ladyman's hostility towards *a priori* metaphysics, note that Schaffer's dismissal of *a priori* arguments in favour of fundamentalism is much too quick.

The question that we face now is whether the idea that levels are characterized by a sequence of ontological dependence is compatible with the fundamental supervenience base approach. So, what we are looking for is a sequence of ontological dependence that starts from macrophysical objects and terminates, supposedly, at a fundamental supervenience base. More accurately, we are looking for a sequence of *generic* necessitation (GN):

(GN) *x* cannot exist unless something is an *F*

Where *F* is a general term – that is, *x* cannot exist unless another object of the type *F* exists (Correia 2008: 1015). For instance, any given water molecule cannot exist unless hydrogen atoms exist. But generic necessitation defined in such a way will not be sufficient for us, as it seems to assume a mereological structure ordered by part-whole relations – something which we were hoping to avoid. Specifically, we wish to avoid a commitment to point-like entities. A more appropriate example for our purposes could be the following: a given electron cannot exist unless the universal wavefunction behaves in a specific, 'electron-like' manner, in a certain locality. For the sake of simplicity though, we might as well decide to label this particular aspect of the behaviour of the universal wavefunction as 'an electron'. It is not clear that this example fits the definition of generic necessitation. Moreover, it should be noted that this description already implies the empirically controversial idea that 'wavefunction-stuff'[5] has an objective existence – this will severely limit our options regarding the interpretation of quantum mechanics. However, the description can certainly be amended according to one's preferred interpretation of quantum mechanics, so we do not need to make any commitments in this regard here.

It is unfortunate that all the usual accounts of ontological dependence are formulated with reference to entities of some sort, but there is no compelling reason why this should be the case. When considering the ontological basis of macrophysical objects, it is perhaps more natural to think about their dependence on a specific range of values for the fundamental physical constants, or on certain physical principles such as the Pauli Exclusion Principle – we will consider these requirements in the next section. It is fairly straightforward to amend the definition of generic necessitation in such a way that these requirements can be taken into account. We could formulate it as follows (GN*):

(GN*) *x* cannot exist unless *F* is appropriately instantiated

Where *F* is a general term as before. This new definition changes the picture somewhat: we can now, for instance, refer to aspects of the universal wavefunction as part of a generic necessitation sequence. We could say that a particular elephant cannot exist unless elephanthood is appropriately instantiated, where 'appropriate instantiation' can be defined according to one's preferred theory of quantum mechanics. If this theory is committed to wavefunction realism, then the requirement of an 'appropriate instantiation' would be fulfilled by an 'elephant-like' distribution of 'wavefunction-stuff', that is, by 'elephant-like' behaviour of the universal wavefunction in a certain locality. Similarly, the definition works for competing theories such as Ghirardi's (e.g. 2008) mass density interpretation – just replace 'appropriate instantiation' with a description of the mass density. Note that the definition works even if one prefers a theory which *does* explicitly commit to particles as fundamental entities: 'appropriate instantiation' could then be interpreted simply as the existence of an object of type *F*, as in the original example.

Now that we have a clearer understanding of what the levels metaphor amounts to, we can proceed to examine whether there are good reasons to think that there is a fundamental supervenience base where the sequence of generic necessitation ends. In the next section we will analyse the prospects for an argument for fundamentalism primarily in the light of the available evidence from current physics. However, some methodological considerations will also be made, and the possibility of *a priori* input is also considered.

IV A proposed argument for fundamentalism

In this section we will examine a potential argument for the existence of a fundamental level. The argument relies on empirical evidence as well as speculative physics, but there are some methodological considerations as well as *a priori* elements which may support for it. The argument is by no means conclusive and it is presented primarily for the purposes of illustration, but I hope that by analysing this argument we can get a clearer idea about our prospects of settling the debate about fundamentalism. We begin with an outline of the argument:

1. There are macrophysical objects.
2. Certain things are physically necessary for the existence of macrophysical objects e.g., the laws that govern molecular binding.
3. These laws require certain regularities on the microphysical level e.g., that fundamental physical constants fall within a specific range.
4. The required regularity of the microphysical level would not be possible without a fundamental supervenience base.
5. Therefore, there is a fundamental level.

The first premise ought to be uncontroversial, but each of the remaining premises will be defended. The fourth premise is by far the strongest, and also the only premise which could perhaps be supported by *a priori* considerations. The modality in the fourth premise can be interpreted either as metaphysical or physical[6] – this will have a major impact on its strength. The stronger, metaphysical reading would also require *a priori* input. The empirical content concerns primarily the existence conditions of macrophysical objects given the actual laws of physics. Let us now consider each of the remaining premises in turn.

2. Certain things are physically necessary for the existence of macrophysical objects e.g., the laws that govern molecular binding.

This premise is fairly trivial if the laws of physics are considered to be physically necessary, but it is worth spelling out its implications in some more detail as we will need to look into these details later in any case. We could also consider a much stronger version of this premise, according to which the laws governing the emergence of macrophysical objects are *metaphysically* necessary, but for the purposes of the argument that I outlined this is not needed.

For there to be any macrophysical objects, the forming of such objects must be possible. I wish to consider the minimal conditions for the possibility of stable macrophysical objects. A natural way to spell out these minimal conditions is in terms of the physical laws that govern the forming of macrophysical objects. For instance, it is necessary for the existence of (most) stable macrophysical objects that molecules can bind together to form molecular complexes, albeit some covalently bonded networks of carbon atoms such as diamonds or graphite lattices are examples of macrophysical, extremely large molecules. At any rate, it is necessary for any macrophysical object that atoms are able to form bonds to create stable molecules, and further, that subatomic particles are able to form stable atoms. So, what enables atoms to form bonds and subatomic particles to form atoms? Well, the binding of molecules and atoms is dependent on the electron configuration of individual atoms, which in turn depends on the energy levels of specific electrons and is moderated by the Pauli Exclusion Principle.[7] Similarly, the manner in which subatomic particles form atoms is dependent on the individual charges of subatomic particles, namely the negative charges of the electrons and the positive charges of the protons, where each proton consists of three quarks which make up the total charge of the proton.

At this point it should be noted that although I have been referring to subatomic *particles*, we have no reason to assume mereological atomism here – in fact it is a commitment we wish to avoid. All we need is a microphysical arrangement which enables the possibility of macrophysical objects. Accordingly, whether or not we view electrons as particles, we know that their behaviour is subject to the Pauli Exclusion Principle. More specifically, if we have two identical and indistinguishable electrons, the wavefunction for the system of those two electrons must be anti-symmetric.[8]

Let us consider a case of covalent bonding in a hydrogen molecule. For a covalent bond to form between two hydrogen atoms, the complete wavefunction of the system, which combines the spin and spatial wavefunctions, must be anti-symmetric. Accordingly, if the spin wavefunction is symmetric, then the spatial wavefunction must be anti-symmetric. However, only a symmetric spatial wavefunction will lead to bonding, as we need an attractive force between the hydrogen atoms, enabling them to share a pair of valence electrons. Hence, since the Pauli Exclusion Principle requires the complete wavefunction to be anti-symmetric, we know that the spin wavefunction must be anti-symmetric for a bond to form. We also know that a third hydrogen atom cannot bond with the two-atom hydrogen molecule, as it would necessarily have an anti-symmetric wavefunction with one of the hydrogen atoms, and would therefore be repelled. As should be clear from this description, the Pauli Exclusion Principle is crucial for the process of covalent bond forming.

In the case of ionic bonds, such as the bond between sodium and chlorine in sodium chloride molecules, the Pauli Exclusion Principle is responsible for the repulsive force between Na^+ and Cl^- ions. As the ions come closer and the wavefunctions of their electrons start to overlap, the Pauli Exclusion Principle requires that these electrons cannot be in the same quantum state. The situation is resolved by a change in the energy levels of the electrons so that no two identical electrons occupy the same quantum state. The change in the energy levels of electrons requires energy and results in the repulsive force, typically called *Pauli repulsion*, that prevents the ions from coming any closer together. The result is a stable sodium chloride molecule.

Why is the Pauli Exclusion Principle so important the argument? Well, since it governs both the bonding behaviour of atoms and the electron configuration of individual atoms, it is crucial for the emergence of stable macrophysical objects. It is sometimes said that the Pauli Exclusion Principle is responsible for the space-occupying behaviour of matter, as it prevents atoms from collapsing together: the electrons must occupy successively higher orbitals to prevent a shared quantum state and hence not all electrons can collapse to the lowest orbital.[9]

Incidentally, it is the Pauli Exclusion Principle that explains why subatomic particles can behave in a manner which is so different from macrophysical objects. The principle is key to understanding why fundamental physics cannot be viewed as a network of 'microbangings' – something that Ladyman and Ross (2007: 4) accuse metaphysicians of doing in their search for 'genuine causal oomph'. Well, I have to agree that the 'microbangings' model of fundamental physics is not very fruitful, but, contrary to what Ladyman and Ross claim, the idea of levels of reality does not need to be intimately connected with that model. Indeed, the model of classical physics, which is based on these 'microbangings', is completely unable to explain why atoms do not collapse inwards – we need the Pauli Exclusion Principle for that.

The physical necessity of the Pauli Exclusion Principle for the emergence of matter appears to be uncontroversial, but the stability of matter requires more than that, which brings us to our third premise.

3. These laws require certain regularities on the microphysical level e.g., that the fundamental physical constants fall within a specific range.

One of the important fundamental physical constants for the stability of matter is the *elementary charge*, namely 1.6021892 × 10^{-19} coulombs. This is the charge of protons, whereas electrons have a negative charge of equal strength. Interestingly, the charge of all other freely existing subatomic particles that have a charge is either equal to or an integer multiple of the elementary charge. Quarks, which are the constituents of protons, have charges that are integer multiples of one third of the elementary charge, but they are not freely existing. The total charge of the atom is of course neutral. The picture gets somewhat more complicated when details about the underlying fundamental forces are introduced; for instance, the nucleus holds together in virtue of the *strong force*, which overpowers the repulsive forces between the positively charged quarks that make up the protons. Now, what is interesting for us is whether fundamental physical constants, such as the elementary charge, are physically necessary for the stability of matter. In other words, if the fundamental constants had been different, would atoms still be stable?

It has been suggested that at least some of the fundamental physical constants do vary over time, specifically the *fine structure constant* (sometimes called the electromagnetic force coupling constant), which characterizes the strength of the electromagnetic interaction, and the *electron to proton mass ratio*. This variation has been determined with the help of astrophysical observations of quasars (Uzan 2003). Recent research has focused on trying to determine limits for the possible variation of physical constants – especially interesting here are the values of these constants during the primordial nucleosynthesis (cf. Ivanchik *et al.* 2001). However, there are serious experimental limitations in determining whether fundamental physical constants do indeed vary over time: observations commonly entangle a certain set of constants, or assume that certain constants do not vary (Uzan 2003).[10] It is also worth noting that if all the fundamental physical constants were to vary together so that their ratios would remain the same, it would presumably be impossible to establish this observationally.

If we hope to establish some limitations to the possible variation of fundamental physical constants in such a way that this variation would not jeopardize the stability of matter, then we should direct our attention towards the values of the constants relative to each other. It is plausible that if all the constants were to change so that their proportions would *not* change, then the stability of matter might not be in jeopardy. However, if we change just one of the constants, this would be much more likely to cause problems. Take the fine structure constant, α: it is a dimensionless constant which is expressed in terms of other physical constants, namely the elementary charge, the *electric constant*, the *Planck constant*, and the *speed of light*; the numerical value of α^{-1} is just over 137. Now, a dimensionless constant serves our purposes very well, as a change in a dimensionless constant implies that the proportions between constants have changed. The electron to proton mass ratio, β, is another good example. Indeed, had either one of these fundamental physical constants been of a slightly different value, then macrophysical phenomena as we know it would not have been possible:

> For example, if we were to allow the ratio of the electron and proton masses $\beta = m_e/m_N$ and the fine structure constant α to change their values (assuming no other aspects of physics are changed by this assumption—which is clearly going to be false!), then the allowed variations are very constraining. Increase β too much, and there can be no ordered molecular structures because the small value of β ensures that electrons occupy well-defined positions in the Coulomb field created by the protons in the nucleus. If β exceeds about $5 \times 10^{-3} \alpha^2$, then there would be no stars. If modern grand unified gauge theories are correct, then α must lie in the narrow range between about 1/180 and 1/85 in order that protons not decay too rapidly and a fundamental unification of non-gravitational forces can occur. If, instead, we consider the allowed variations in the strength of the strong nuclear force, α_s, and α then roughly $\alpha_s < 0.3\alpha^{1/2}$ is required for the stability of biologically useful elements like carbon. If we

> increase α_s by 4 percent, there is disaster because the helium-2 isotope can exist (it just fails to be bound by about 70 KeV in practice) and allows very fast direct proton + proton → helium-2 fusion. Stars would rapidly exhaust their fuel and collapse to degenerate states or black holes. In contrast, if α_s were decreased by about 10 percent, then the deuterium nucleus would cease to be bound, and the nuclear astrophysical pathways to the build up of biological elements would be blocked. Again, the conclusion is that there is a rather small region of parameter space in which the basic building blocks of chemical complexity can exist. (Barrow 2001: 147.)

It should be emphasized that it would not be physically possible to vary individual constants in the manner imagined in this scenario: a change in one constant would have ramifications throughout the range of physical constants, as Barrow notes. However, it does seem clear that fundamental physical constants must fall within a specific range to enable the physical possibility of the emergence of macrophysical objects, which is exactly what the third premise states.

4. The required regularity of the microphysical level would not be possible without a fundamental supervenience base.

The fourth and final premise is no doubt the one that does the most work, which is why the rest of this section will be devoted to it. It may seem difficult to substantiate the claim that a fundamental supervenience base is necessary for the microphysical orderliness which is required for the stability of matter. Certainly, no amount of empirical research could establish that it is a *metaphysical necessity*. However, that a fundamental level is a *physical necessity* for the stability of matter may be something that we can support with empirical evidence.

What we are looking for is perhaps closest to what Hüttemann (2004: 7) calls laws of the micro-level which govern the systems on the macro-level, although I will not address Hüttemann's case against such laws here. We have already seen that the Pauli Exclusion Principle, for instance, is a good candidate for such a law. A further look into quantum mechanics is needed though if we hope to find the best candidates for governing microphysical laws and to get some idea as to what the fundamental supervenience base could be like. This is where competing answers to the *measurement problem* enter the picture, and where current physics is not able to give us a determinate answer.[11] It would not be fruitful to consider all the different interpretations of quantum mechanics and their implications towards fundamentalism here. Instead, I will focus on one particular, speculative theory, loop quantum gravity (henceforth LQG). LQG may not be the most popular interpretation of quantum mechanics, but it is the most interesting theory to examine in this connection because it would seem to offer support for the fourth premise of the argument for fundamentalism. LQG may or may not be supported by future experiments, but given that the jury is out on the interpretation of quantum mechanics, we can hope to do little more but speculate at this point. But before going into the details of LQG, the requirements for a fundamental supervenience base should be formulated more precisely.

Recall that I wish to view levels as a sequence of ontological dependence. It is time to ask: why think that the sequence must terminate (or continue indefinitely only as a repetitive, ontologically 'boring' sequence)? This question could be seen as a variation of the so called anthropic question, which is concerned with the necessary conditions for the existence of complex life in the universe (e.g. Barrow 2001). The *anthropic principle* comes in many forms. One of the weaker versions of the principle suggests simply that the universe must be such that it allows for observers. Stronger forms of the principle suggest that the connection between the values of the fundamental constants appropriate for the emergence of complex life are necessitated: the universe could not have come into being without the emergence of complex, intelligent life; sometimes it is even considered to be the sole purpose of the universe. Understandably, the anthropic principles have been the subject of very critical discussion, which we do not need to go into. Rather than the emergence of complex life, my focus has been on the necessary conditions for the existence of macrophysical objects in general, and this will hopefully help to avoid the anthropocentric connotations of the anthropic question. Accordingly, I am only interested in the existence of a fundamental level in those worlds where macrophysical objects are possible, such as the actual world – nothing that has been said rules out a possible world which lacks a fundamental level. However, according to the strong reading of the fourth premise, which involves metaphysical instead of physical necessity, this world would also lack macrophysical objects. In its strong form, the argument for fundamentalism has a structure similar to the strong anthropic principle; similarly, the weaker version of the argument corresponds with the weak anthropic principle as it concerns only the actual world – the actual universe must be such that it allows for the existence of macrophysical objects. So, to get to the bottom of the argument, we must consider the status of the conditions for the emergence of macrophysical objects.

We already have a fairly good idea about the requirements for the emergence of stable, macrophysical objects, as I have considered these requirements in connection to the other premises. The sequence of generic necessitation produces a list of requirements for the stability of matter, including physical principles such as the Pauli Exclusion Principle and a limited fluctuation of the fundamental physical constants. This list of requirements must itself be stable, as otherwise the sequence of generic necessitation would collapse; this is due to the extreme fragility of macrophysical objects, which is illustrated by the narrow ranges for the values of physical constants. Finally, the requirement for stability dictates that the list cannot be infinite: it must at the very least terminate with a repetitive description, which would be the case if we have an ontologically 'boring', infinite repetition of structure, i.e. turtles all the way down. If it could be shown that the stability of matter requires a finite sequence of generic necessitation by metaphysical necessity, then we would have an *a priori* argument in favour of the stronger reading of the fourth premise. There may be some hope for such an argument on the basis of what has already been said, but presently I am not concerned to defend such a strong reading of the fourth premise. In any case, we can offer some further methodological support at least for the weaker reading.

Consider for a moment what the implications would be if the list of requirements for the stability of matter were complex and infinite. It seems that we would then need an infinite number of fundamental physical constants which govern the behaviour of the complex, infinite microphysical structure, for if there were a limited number of them, then the structure would eventually have to repeat itself and hence it would be ontologically 'boring'. All of these constants would also have to fall within an appropriate range to enable the bonding behaviour required for the emergence of stable macrophysical objects. Even further, there would have to be an infinite list of physical principles which governs this complex and infinite, yet stable structure. All this would surely make the possibility of stable macrophysical objects extremely unlikely, if not impossible. Hence, a finite or at least an ontologically 'boring' structure would appear to be much more probable. Appearances may of course be deceptive, but the conclusion is in line with typical standards of scientific explanation; Ockham's razor suggests that we should go for the theory which makes the fewest assumptions, and a fundamental supervenience base is clearly a more parsimonious choice than an infinite, complex chain of dependence that commits us to the existence of an infinity of unobserved laws and fundamental constants.

This is my case for the fourth premise. It may not be conclusive, but I do think that is shifts the burden of proof onto the anti-fundamentalist.

V Reconciling quantum mechanics with fundamentalism

Even if we accept the ontological appeal of fundamentalism, the challenge of reconciling it with quantum mechanics still remains. The jury is out on the interpretation of quantum mechanics, but we should be able to accommodate fundamentalism in at least some of the competing theories. Loop quantum gravity may be the most promising option, but before we go into the details, a preliminary requirement should be considered. Given that we want the sequence of ontological dependence to be finite, we should look for a model with a finite geometry. A survey of finitism in geometry is available in Van Bendegem (2010) – several suggestions that might offer some support for our hypothesis are discussed. Note that, for our purposes, it is certainly not necessary to eliminate infinities from the underlying mathematics. Indeed, since the thesis is just that there must be a fundamental supervenience base, we can, for instance, have an infinite lattice-type microstructure, which would be compatible with the idea of an ontologically 'boring' sequence of generic necessitation. One interesting suggestion to this effect, concerning a discrete, periodic lattice-type structure, has been put forward by Alfred Schild, who suggests a model of discrete space-time which involves a *fundamental length*, namely the smallest non-zero interval between lattice points (1949: 29). If there is a fundamental length of the type described in Schild's model, then we are already very close to the idea of a fundamental level. Related models have been developed in Kustaanheimo (1951) and Ahmavaara (1965a, 1965b). The latter proposes a range of values for the finite lattice-type structure which Schild discusses as well.

This early work on finite geometry will not be enough to reconcile fundamentalism with quantum mechanics though, for that we have to move on to loop quantum gravity (LQG), which offers the most promising framework for fundamentalism and for maintaining spacetime discreteness.[12] A number of different versions of LQG are currently being developed, but they have one important factor in common:

> The common theme of these variants is to take seriously spacetime discreteness, which in loop quantum gravity is derived as a result of conservative quantization of continuum classical general relativity, and to use it, instead, as a starting point for the formulation of the fundamental theory. The common point of view is then that the fundamental quantum theory will be discrete. There is no continuum limit in the sense in which lattice QCD [Quantum Chromodynamics] has (presumably) a continuum quantum field-theory limit. Rather, states can approximate classical continuum GR [General Relativity]. (Rovelli 2008: 35.)

And further:

> The central physical result obtained from loop quantum gravity is the evidence for a physical quantum discreteness of space at the Planck scale. This is manifested in the fact that certain operators corresponding to the measurement of geometrical quantities, in particular area and volume, have discrete spectra. According to the standard interpretation of quantum mechanics (which we adopt), this means that the theory predicts that a physical measurement of an area or a volume will yield quantized results. (Rovelli 2008: 37.)

Ladyman and Ross (2007: 172) refer to both Rovelli (2004) and Smolin (2000), two developers of LQG, but they do not consider the implications of their work for the fundamental level hypothesis. However, they do admit that the question of quantum gravity is anything but settled, and if it allows for a fundamental level, as appears to be the case, then current physics is perfectly compatible with the idea of such a level.

Indeed, it is in some recent theoretical work related to LQG that we find direct support for the thesis that a fundamental level is required for the stability of matter (cf. Bilson-Thompson 2006, Bilson-Thompson *et al*. 2007, Hackett 2007, Bilson-Thompson *et al*. 2009). It is especially interesting that theoretical physicists themselves have recognised the philosophical significance of this work:

> In the last century, there have been repeated discoveries of underlying structure. Moving from macroscopic objects, to atoms, to components of the nuclei, to quarks, it has been demonstrated repeatedly that the differences between supposedly fundamental particles are, in fact, merely consequences of the composite structure of underlying reality. It only seems a natural progression that such an approach of looking for underlying structure be used to explain the particles of the standard model. Attempts towards this end, dubbed preon models, met with many obstacles, but still there was something deeper that presented itself as a difficulty. The difficulty is that, as such a process does not have an end, we can continue to suppose that below the currently understood structure is another set of more fundamental particles. This idea quickly becomes unappealing at a philosophical level, or even a practical level, as the question then becomes 'What could make it end?'. The idea that the preons would be as fundamental as possible, such as those in [Bilson-Thompson 2006], provides a way of achieving the desired end. One way to achieve this end is to suggest that the preons be composed of structure within spacetime. (Hackett 2007: 5757.)

On a related note, Bilson-Thompson *et al*. (2009) suggest that the permanence of matter could be explained by a model of this type:

> It has long been hoped that the fundamental particles, of which all matter in the Universe is composed, would turn out to be topological structures of some type. This prospect is appealing because if correct it would indicate that the permanence of matter and its properties (obeying principles like the conservation of electric charge) could be explained in terms of different topological classes, which are isotopically inequivalent. Furthermore it would explain the number and type of different particles (electrons, neutrinos, quarks) in terms of a simple counting exercise, much as the periodic table of the elements can be explained by counting the number of protons in atomic nuclei. (Bilson-Thompson *et al*. 2009: 1.)

In regard to the stability of matter, Bilson-Thompson *et al*. (2007) propose a model of quantum gravity and a topological formulation of the preon model which can be reconciled with the standard model. In particular, they identify the non-geometrical conserved quantum numbers that arise from the proposed model with the quantum numbers of the standard model. Of particular interest for my purposes is their discussion of the link between what they call *microlocality*, which characterizes the dynamics on the level of the proposed model of quantum geometry as well as the LQG model, and *macrolocality*, which characterizes the dynamics on the level of classical spacetime geometry. The question is, how can we reconcile these two notions of locality? The reason why this question is of crucial importance for the stability of matter is that unless the two notions of locality coincide, we have no means to explain how classical spacetime geometry can emerge from quantum geometry. Bilson-Thompson *et al*. (2007) rely on some recent work in quantum information theory to solve this puzzle, and propose a pre-geometric solution: the microlevel can be regarded as a quantum information processing system, from which spacetime emerges as ‘the collection of events that are the interactions of the excitations of an underlying pre-spacetime quantum theory, with matter being also emergent as these same excitations’ (p. 3990).

So, it appears that fundamentalism is perfectly compatible with the most recent work in quantum mechanics. The minimal result of this discussion is that a fundamental level is metaphysically possible and at least as plausible as an infinite descent – indeed, if we respect traditional virtues of scientific explanation, fundamentalism appears to be the preferred choice. The empirical part of the story will no doubt remain open for the foreseeable future, and perhaps it will never provide absolute certainty about the existence of a fundamental level, or lack thereof, but the recent advances in loop quantum gravity make the idea plausible – those of us who find infinite sequences of ontological dependence unsettling can at least take comfort in that.

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1 See also Hüttemann (2004) and Papineau (2008).

2 A good introduction to the notion of ontological dependence is Correia (2008); see also Lowe (2005) and Fine (1995).

3 According to which 'all supervenes on the distribution of local, fundamental qualities in spacetime' (Schaffer 2003: 498).

4 Epiphenomenalism claims that 'all causal powers inhere at the fundamental level' (ibid.).

5 'Wavefunction-stuff' is a term used by Lewis (2006) in his description of the wavefunction realism interpretation of the GRW theory of quantum mechanics. Here it is used simply for the purposes of illustration.

6 The notion of 'physical necessity' is used in the sense of necessity in virtue of the actual, true laws of physics, whatever they may be. This allows for the possibility that the laws of physics as we know them may not be the true laws of physics. I consider it to be an open question whether there are possible worlds with alternative laws of physics, but these would not be physically possible in the sense that the notion is used in here; they may or may not be metaphysically possible.

7 The Pauli Exclusion Principle states that no two identical fermions can have the same quantum number at the same time.

8 See the *HyperPhysics* project for details (Nave 2006).

9 For an early proof of the stability of matter, see Dyson & Lenard (1967a, 1967b). For a proof of the stability of matter in rather more extreme conditions, such as neutron stars, see Lieb, Loss & Solovej (1995). Finally, see Lieb

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(2003) on the connection between the stability of matter and quantum electrodynamics.

[10] See also Melnikov (1994).

[11] The measurement problem concerns the effect of the observer on the system under investigation – the most famous example of the problem is no doubt Schrödinger's cat. The technical details are related to wavefunction collapse, but we do not need to dwell on them.

[12] See Rovelli (2008) for a comprehensive survey.

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